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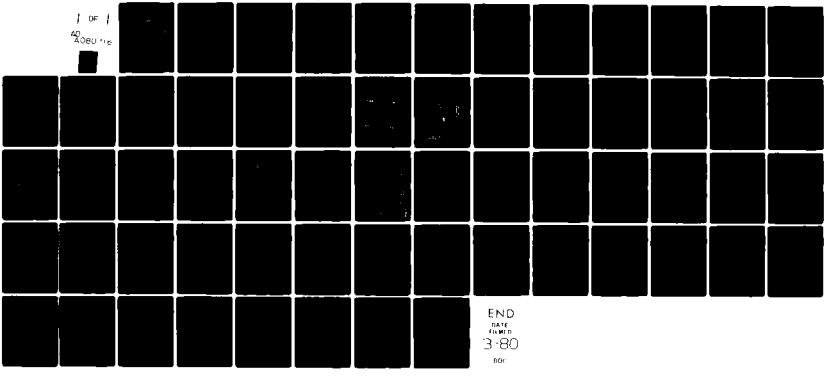

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PHYSICAL, CHEMICAL AND ENGINEERING PROPERTIES OF RESIDUAL LIMESTONE SOILS AND CLAYS

LEVEL II

FINAL REPORT

Wayne C. Isphording

2 January 1980

U. S. ARMY RESEARCH OFFICE
GRANT NUMBER DAAG29-76-G-0328

UNIVERSITY OF SOUTH ALABAMA

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Clay mineralogy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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16 cone penetrometer compression tests and 11 direct shear measurements. The major factors influencing and controlling the development of residual limestone soils are discussed, as well as differences that result from their formation in Temperate versus Tropical climates. Composition of insoluble residues present in the parent limestones, regional relief, and duration of the dry season were identified as factors most strongly affecting the mineral and chemical composition of the residual clays. Statistical analyses were also carried out to assess the strengths of inter-relationships among the different variables measured and to identify those most significant in controlling the strength of the soils.

PHYSICAL, CHEMICAL AND ENGINEERING PROPERTIES OF RESIDUAL LIMESTONE SOILS AND CLAYS

W. C. Isphording
Principal Investigator

ABSTRACT

Baseline data was collected on soils and clays originating from the weathering of limestone bedrock. 79 Neutron Activation analyses are included for each of 21 trace metals and, similarly, the results of 129 analyses for 8 major oxides are also appended. Information is presented on the results of 112 mineral analyses, 79 size frequency analyses, 73 specific gravity determinations, 96 analyses for Liquid Limit, Plastic Limit and Plasticity Index, 16 cone penetrometer compression tests and 11 direct shear measurements. The major factors influencing and controlling the development of residual limestone soils are discussed, as well as differences that result from their formation in Temperate versus Tropical climates. Composition of insoluble residues present in the parent limestones, regional relief, and duration of the dry season were identified as factors most strongly affecting the mineral and chemical composition of the residual clays. Statistical analyses were also carried out to assess the strengths of inter-relationships among the different variables measured and to identify those most significant in controlling the strength of the soils.

TABLE OF CONTENTS

INTRODUCTION

The purpose of this investigation was to carry out a detailed study of the residual soils and clays that develop when limestone bedrock weathers. The need for such "base-line" information is apparent when it is realized that the comprehensive publication issued by the U. S. Department of Agriculture entitled "Soil Classification, 7th Approximation (1960)" contains not one truly representative profile of a residual limestone soil in the 107 profiles described in the work. Further, though this publication also serves as the basis for the proposed "world soils classification system", the omission of any reference to limestone-derived soils forces the user to assume that all such soils will conveniently "fit" into one of the groupings that were, for the most part, developed to describe Temperate Zone soils lying on other types of bedrock. Though the USDA's study does prevent these soils from being described by the archaic, nebulous terms "terra rosa" and "rendzinas", their inclusion with the new catagories "Mollisols", "Alfisols", "Oxisols", "Inceptisols", etc., has meaning only to those concerned with soil taxonomy. These groupings provide the soils engineer or geologist with little in the way of the information that he is interested in, namely the physical, engineering, mineralogical and chemical properties of the

soils. Indeed, for an engineer or geologist to learn that they are dealing with a regolith that might fall into the catagory "Ochrepts, sub-group Rendollic Eutrochrepts" would either send them into paroxysms of laughter (or deep depression) or would cause them to suggest that the user be sent to a home for the "permanently confused"!

Thus, though the literature fairly abounds with information dealing with soils developed on many other major rock types, and is full of references to the genesis, diagenesis, chemistry, etc., of limestones themselves, it is paradoxical to note that few descriptions have been published, to date, with regard to their weathering products (see, for example, Van Baren, 1928). Common practice, for years, has been to assume that the weathering of limestones either produces a red soil ("terra rosa") or a black soil ("rendzina") and that regardless of climate, stage of geomorphic development, drainage, etc., the physical, chemical and mineralogical properties of each are more or less constant. The study carried out for the Army Research Office challenges these generalities and provides detailed information on both Tropical and Temperate Zone residual limestone soils of the following types:

(1) 79 Neutron Activation trace element analyses of samples for the following elements:

Rubidium	Europium	Ytterbium
Cesium	Lutetium	Samarium
Barium	Hafnium	Zinc
Scandium	Thorium	Antimony
Sodium	Iron	Cerium
Potassium	Tantalum	Cobalt
Lanthanum	Chromium	Manganese

(2) 129 Atomic Absorption major element analyses for the following oxides:

Silica	Calcium
Alumina	Sodium
Iron	Potassium
Magnesium	Water

(3) 112 X-ray diffraction mineralogical analyses for all clay mineral and major oxides and silicates.

(4) 37 Spectrophotometric iron analyses for iron in the forms listed below in order to study the effect of iron on various physical and engineering properties.

Total iron
Total extractable iron
Extractable iron as Fe^{+2} (ferrous iron)
Extractable iron as Fe^{+3} (ferric iron)

(5) 79 Size frequency distributions carried out using ASTM Sieve and Hydrometer techniques.

(6) 73 Specific gravity analyses using the ASTM pycnometer method.

(7) 96 Liquid Limit, Plastic Limit and Plasticity Index determinations.

(8) 11 unconfined compression analyses (using Direct Shear) and 16 analyses using a Cone Penetrometer.

The preceding, almost certainly, represents one of the more intensive attempts to gather baseline data on soils and clays developed on one specific type of bedrock and should provide a considerable amount of previously lacking basic information for the pedologist, geologist and engineer. Some of this data has already been disseminated to the scientific community by means of two published papers (Isphording, 1978; Isphording, 1979) and seven papers presented on various aspects of the study at meetings of professional societies (see Bibliography, Appendix 1). Two additional papers are nearing completion for publication

and two others are scheduled for presentation at forthcoming meetings (American Association of Petroleum Geologists, June, 1980, Denver, Colorado; American Institute of Professional Geologists, September, 1980, Mobile, Alabama).

By way of summary, however, the major conclusions will be reviewed in this report as well as new information obtained from recently completed statistical analyses of the data. The more important data matrices are included as appendices to this report and all data discussed is stored on disc file at the University of South Alabama Computer Center and is available to any interested user by request to this investigator.

RESULTS OF INVESTIGATION

General Discussion

Critical to the understanding of limestone soil genesis is the realization that, with respect to their weathering behavior, limestones are unique among all major rock types in their susceptibility to attack, and dissolution, by meteoric and groundwaters. Whereas the weathering of one cubic meter of granite results in the production of a volume of clay and residual quartz greater than that of the original rock, the weathering of an equal volume of limestone produces a volume amounting to only a fraction of a cubic centimeter, under most circumstances. This arises from the fact that the only minerals capable of producing such clays are the so-called "insoluble residues" that remain after the parent limestones have weathered. The quantities of

these materials are always small because the nucleation of calcite or aragonite is markedly inhibited in depositional basins receiving excessive amounts of detritus. Where large quantities of silt and clay are supplied to the depositional basin, precipitation of limestone ceases and the muds form interbedded lenses of shale within the limestones, rather than being incorporated as impurities in the limestones themselves. For this reason, to examine factors affecting the development of limestone-derived residual soils, it was first necessary to obtain samples from an area containing no interbedded clastics that would modify the residual limestone material with their own weathered debris. The Yucatan Peninsula of Mexico provided an ideal site for such a study because, not only is it the largest area of continuously exposed carbonate rock in the Gulf Coast, but also possesses no major surface streams that could transport detrital material northward from the Chiapas Highlands of southern Mexico and northern Guatemala. Hence, all clays present on the Yucatan Platform are either residual from the parent limestones or have formed as primary minerals, by authigenesis. The presence of carbonate rocks to depths of several thousands of feet in test wells drilled by Petroleos Mexicanos testifies that such conditions have persisted in the region throughout the entire Tertiary Period. Further, the Peninsula enjoys the distinction of possessing three major stages of geomorphic development (Figure 1) ranging from youthful in the recently emerged Northwestern Coastal Plain, early maturity in the Northwestern Coastal

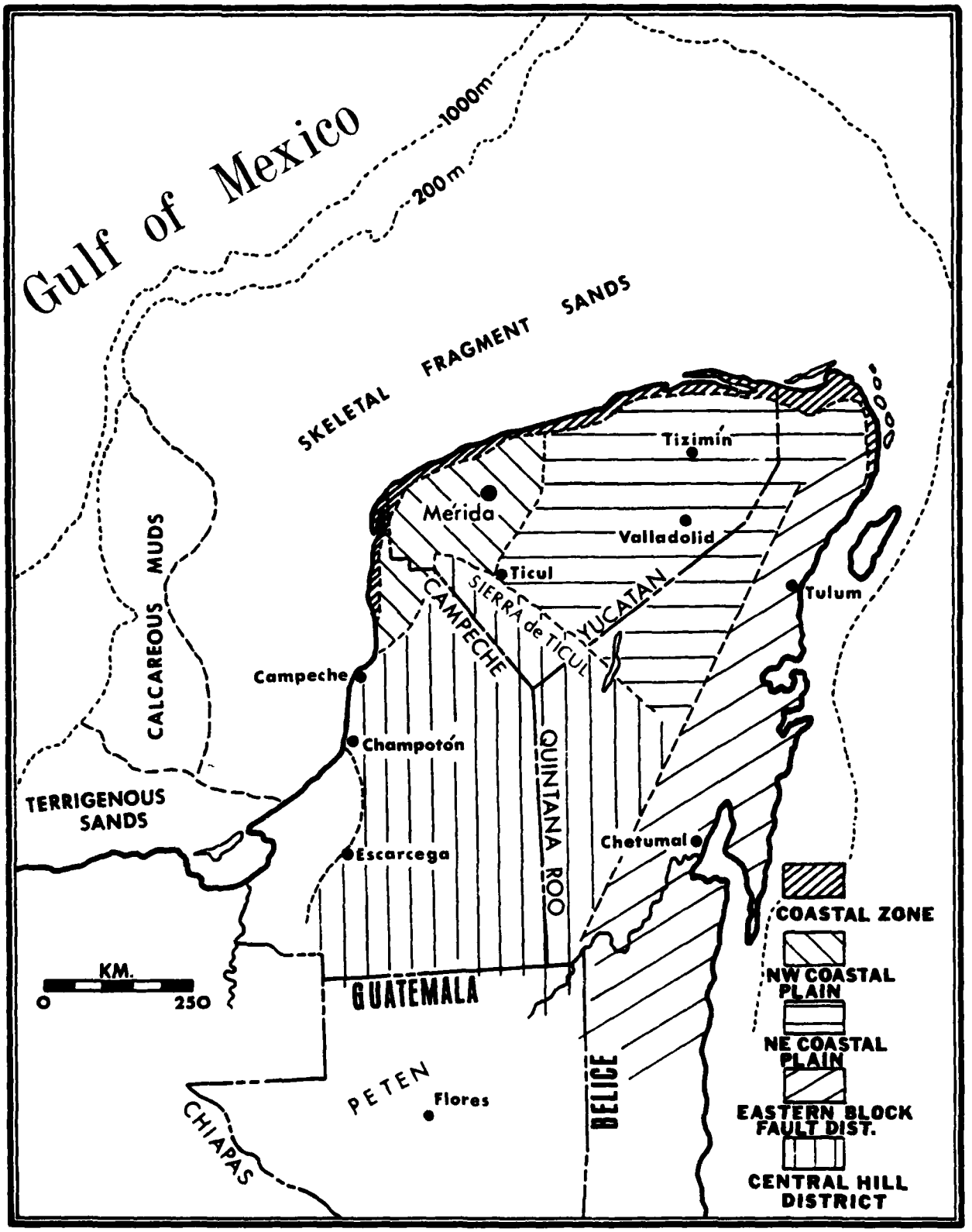


FIGURE 1 — Map of Yucatan Peninsula showing principal physiographic provinces.

Plain, and mature to advanced maturity in the Central Hill District (see Isphording, 1975). Collection and analysis of soil samples from each of these three areas have thus allowed the major mineralogical and geochemical trends to be identified during the progressive development of a residual limestone soil profile. Similarly, major differences in annual rainfall in different areas of the Yucatan Peninsula have also allowed the importance of this variable to be assessed. Because the limestones throughout the peninsula do enjoy the unusual property of lacking interbedded clastic units, samples were also collected farther to the south in Guatemala, Honduras and Costa Rica to examine the effects of a high clastic influx on the subsequently forming soils. To evaluate the effect of cooler climates on the mineralogy, chemistry and physical properties of residual soils, samples were collected in the United States from sites in Texas, Missouri, Alabama, Tennessee, Kentucky and Michigan.

Soil Genesis

Discussion of the factors that influence and control the formation of residual limestone soils are discussed, in detail, in Isphording (1978, 1979). Basically their development was found to be determined by two main factors: (1) the amount, and type, of insoluble residue in the parent rock (which is a function of conditions existing in the land areas adjacent to the depositional basin) and (2) the regional relief.

With respect to the former, soils developing on limestones that were deposited adjacent to land areas undergoing continental uplift or volcanism were found to be dominated by the clay minerals illite and montmorillonite, respectively. Hence, the brown and black soils of northern Guatemala and central Texas are rich in montmorillonite (smectite) clays that were produced by the weathering of volcanic detritus originally incorporated in the limestones during their precipitation in Cretaceous and early Tertiary seas. Present climatic conditions in both regions (dry in Texas and continuously wet in northern Guatemala) have acted to preserve the smectite clays and have retarded their natural tendency to alter, sub-aerially, to kaolinite. Residual soils forming on limestones adjacent to the Ozark Dome, in Missouri, and those developing on limestones of the Cumberland Plateau in Alabama, Tennessee and Kentucky were originally deposited in the seaway adjacent to the rising Appalachian landmass during the Paleozoic and are, in contrast, dominated by quartz, illite and lesser amounts of kaolinite. The illite, which dominates these clays, is largely detrital in origin and has been derived largely from weathering of exposed shales in the source lands and to a lesser extent by marine alteration of other clays (chlorite and montmorillonite). The kaolinite present is chiefly the product of alteration of feldspar minerals in the adjacent land areas but some has probably formed by alteration of the abundant illitic clays, following their exposure to atmospheric weathering.

Where deposition of the limestones took place far from a source of clastic influx, as was the case for limestones precipitating on the Yucatan Platform, a different mineral suite is observed. Where the clays are in an early stage of development, the original insoluble constituents of the parent limestones are reflected in the mineralogy of the youthful soils. Primary chlorite and illite are observed on X-ray diffractograms (see Isphording, 1978), along with iron oxides and poorly crystallized kaolinite that is just beginning to develop by alteration of the illite-chlorite clays. Where rainfall is seasonal (i.e., a distinct dry season is present), gibbsite or boehmite may be found along with the other constituents. As thickening of the profile continues by accumulation and weathering of the insoluble residues, the original minerals become altered and eventually the soils become almost wholly composed of kaolinite and iron oxides. Higher silica activities in the inter-particle pore waters of these mature clays act to prevent the formation of aluminum oxide minerals and, for this reason, gibbsite and boehmite are largely absent in advanced stage (mature) residual limestone soils.

Though other factors, such as elevation, amount of vegetative cover and annual rainfall may act to exert some influence on the resulting chemistry and mineralogy of the soils, by far and away the second most important factor controlling the composition of the soils is the regional relief. This factor is of such paramount importance in

karst terranes that there is little exaggeration in saying that "in the absence of relief, there is weathering and solution of limestones, but little accumulation of residual soils"! Because of the small amount of insoluble residues present in most limestones, the slow rates of accumulation and the permeable nature of most limestones, much of the insoluble residues liberated by solution of the parent rock are carried off by rainwater seeping into joints and fractures. Only when solution has continued for a sufficient time to permit development of depressions on the karst surface does accumulation of the small amounts of clay and oxides begin to take place. As more and more clays are washed into the depressions, joints and cracks begin to "seal" and development of a soil begins. Granites, basalts, shales and other non-carbonate rocks have no such strong dependency on the initial formation of relief before accumulation can take place and, in fact, many feet or even tens of feet of residual soils may form on such rocks in terranes having minimal relief (see Clemency, 1977). Hence, the development of relief in a karst terrane, in the absence of faulting or folding, is a gradual, progressive phenomena which, itself, controls the ultimate thickness of the soil profile. The presence of any thick clays in limestone regions, therefore, must indicate either: (1) the region is in a mature stage of development (assuming the limestones are still flay-lying), (2) the thick clays resulted from early relief generated on the karst surface as a result of folding, faulting and uplift

of the region, or (3) the clays are not, themselves, residual from the limestones but have formed by the weathering of interbedded rocks of a different nature (shales, pyroclastics, etc.).

Chemistry

Major Elements.-- Chemical analyses for the oxides of silicon, aluminum, iron, calcium, magnesium, sodium, potassium and water (as loss on ignition at 900°C) are included as Appendix II of this report. A total of 129 analyses are listed of which 27 are from the United States (or other Temperate Zone locations), 27 are from the Yucatan Peninsula, 23 from northern and central Guatemala and an additional 52 from other locations in the Tropics (Bahamas, Jamaica, Guadeloupe, Costa Rica, etc.). Examination of the data matrix indicated that chemical differences in the residual limestone soils were, expectedly, directly related to observed mineralogical differences and reflected: (1) the climatic conditions existing in the region, (2) the original mineralogy of the trace minerals in the parent limestones and (3) the geomorphic state of development of the area.

With respect to climate, notable differences in the silicon-aluminum-iron oxide ratios were identified when samples from Temperate regions were compared with those from the Tropics. This is shown graphically in Figure 2 where the Temperate Zone samples (those from the United States) are seen to be higher in silica and generally lower in alumina and iron than their Tropical counterparts.

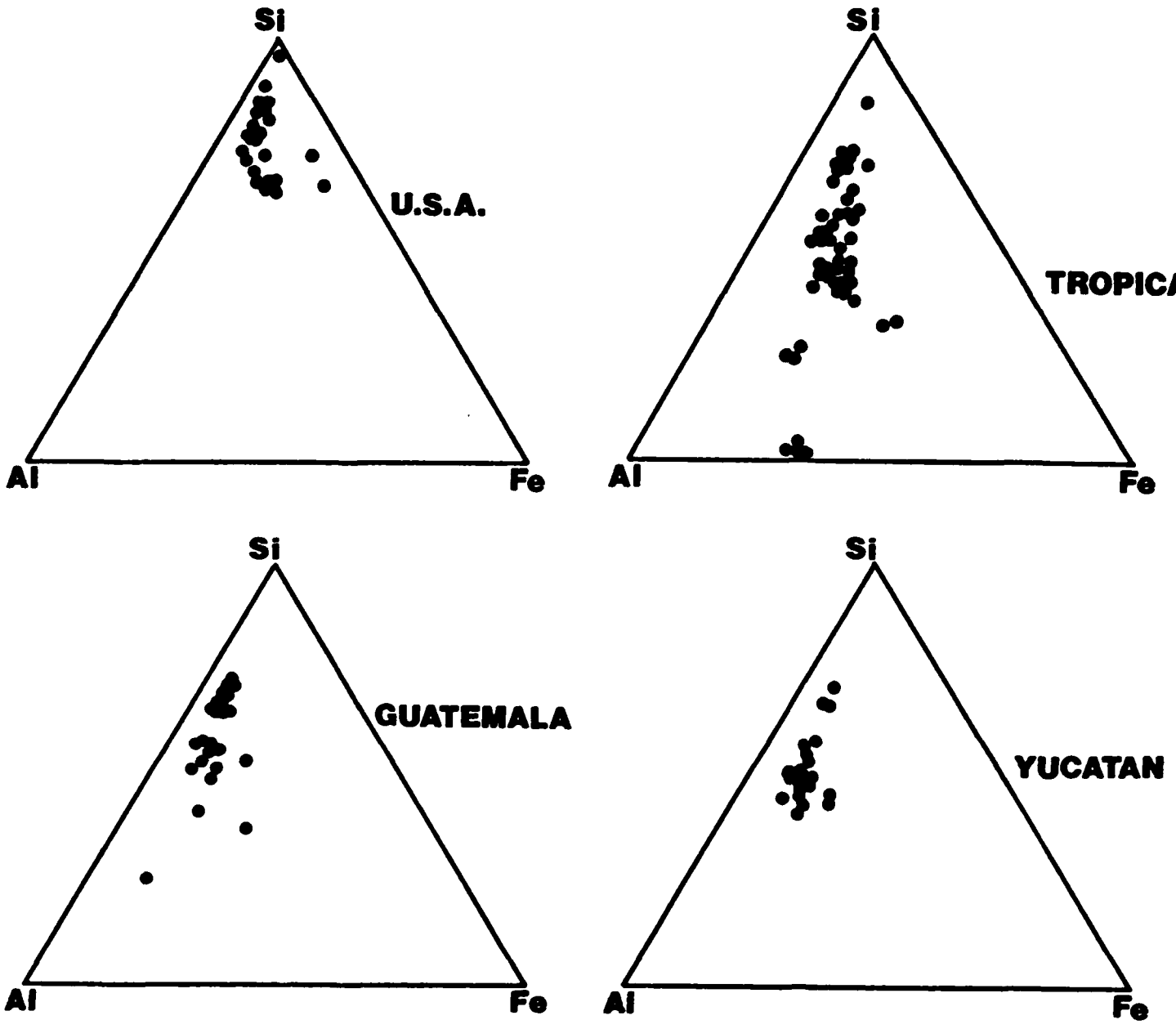


Fig. 2.— Comparison of SiO_2-Al_2O_3-Fe_2O_3 ratios for Tropical and Temperate soils and clays.

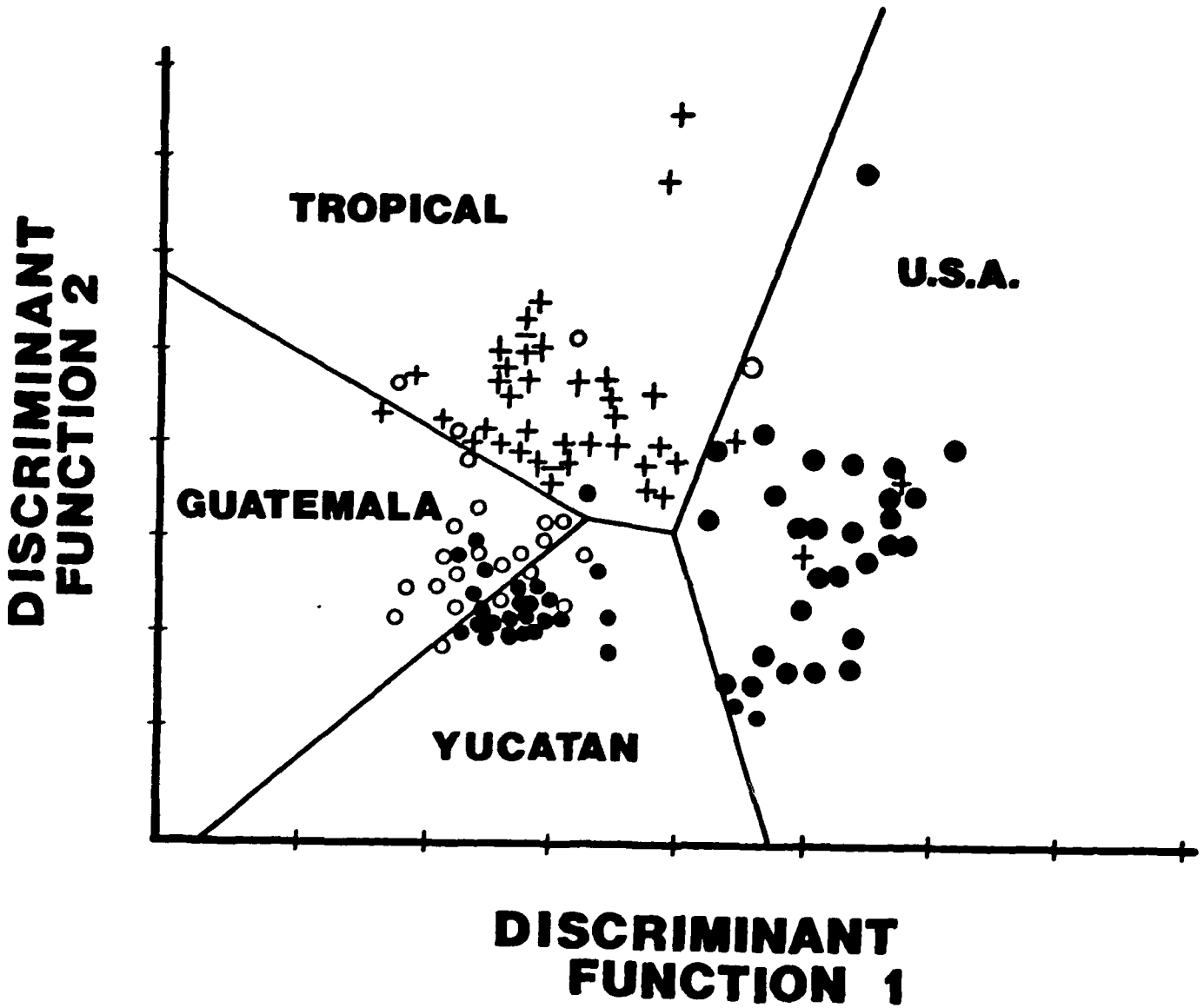


Fig. 3.— Plot of first two discriminant functions for data from 129 Tropical and Temperate soils and clays.

This difference is also manifested in the mineralogy of the samples with, as mentioned previously, Temperate Zone clays being richer in illite and quartz and poorer in kaolinite, gibbsite and iron oxides (see Table 1).

	Yucatan	Guatemala	Other Tropical	United States
Illite	18.8	6.5	9.4	30.2
Kaolinite	47.6	47.5	45.3	13.0
Montmorillonite	12.9	24.8	9.5	14.3
Gibbsite	11.2	3.5	10.0	tr
Iron Oxides	7.7	8.6	15.2	4.1
Quartz	1.7	9.2	16.8	38.3

Table 1.-- Average mineral percentages of clay-size fraction for 129 residual limestone soils. "Other Tropical" includes samples from Bahamas, Guadeloupe, Costa Rica and the Cayman Islands.

The marked difference in overall composition of the major oxides was also seen when the complete oxide analyses for all samples were submitted to a "stepwise" discriminant analysis. The results for this are shown in Figure 3 and it can be seen that by plotting the data from the first two discriminant functions for all samples that no Temperate Zone samples were plotted in the three fields for clays from the tropics and only five of 102 tropical soils were "mis-classified" with Temperate Zone samples. The analysis clearly demonstrates the importance of climate in determining the ultimate chemistry (and mineralogy) of the clays. It should again be emphasized, however, that the term "climate", rather than simply referring to the total annual rainfall, actually involves a combination of annual temperature range, number of months in the "dry" season and, to a lesser extent, total annual rainfall. These variables, in turn, act

in conjunction with the regional relief (geomorphic stage of development) and the original minerals present as "insoluble residues" to determine the sample's chemistry and mineralogy. Total annual rainfall, alone, was not found to correlate well with either the thickness of the soil profile nor the mineralogy of the soil. Where samples were obtained from two areas, one having low to moderate rainfall with low relief, and the other with high rainfall and low relief, the former would always show the greatest amount of profile development and the most "mature" mineralogy (again testifying to the importance and uniqueness of "relief" in controlling soil development in karst terranes). The importance of the presence (or absence) of a distinct dry season was also found significant and determined whether the original trace minerals in the limestones (chlorite, illite, montmorillonite, etc.) would persist or be altered to the thermodynamically more stable phase, kaolinite. If such minerals were present in the parent limestones, their continued presence in the overlying soils required either arid to semi-arid climatic conditions or a continuously wet environment. In the former, the low rainfall prevents cations leached from the clays from being removed by groundwater and retards the natural alteration to montmorillonite; where rainfall is equally distributed throughout the year and the soils remain saturated, the high silica activities similarly act to stabilize Smectite Group clays. If the rainfall is seasonal, however, and drainage is reasonably good, cations are "flushed"

away and the soil becomes dominated by kaolinite and iron oxides. Seasonally high silica activities during the rainy season in the pore waters assure the conversion (by resilication) of aluminum oxides to kaolinite and prevent any large scale formation of either boehmite or gibbsite.

Trace Element Analyses.-- Neutron activation analyses were carried out at Brookhaven National Laboratories on 79 samples from Yucatan and Guatemala to determine the concentrations of the 21 elements listed on page two of this report. The results of these analyses are included in Appendix III. Statistical analyses and examination of the trace element data matrix resulted in the following observations and conclusions:

(1) a general increase in the abundance of most elements was observed with increasing maturity of the profile. Samples from the Northwestern Coastal Plain (the most youthful region) contained the lowest amounts of the various trace metals whereas the Northeastern Coastal Plain (intermediate in profile maturity) and the Central Hill District (the most mature region) contained the highest amounts. Exceptions to this trend were noted only for potassium, rubidium and barium. The decrease of potassium and rubidium, with maturity, can be explained by the fact that potassium is most common as a constituent of illite clays and these become eliminated from the soil mineralogy in Tropical climates as the profile "matures". Rubidium, because of its similar ionic size and charge, is well known to substitute freely for potassium. Hence, any change in the potassium content of a sample is invariably accompanied by a change in rubidium of the same magnitude.

The decrease in barium, in contrast, is undoubtedly related to the fact that it commonly substitutes for calcium. Calcium is present in the clays as small, remnant fragments of bedrock and, as the profile develops, the fragments are dissolved by pore waters charged with carbonic acid. In the

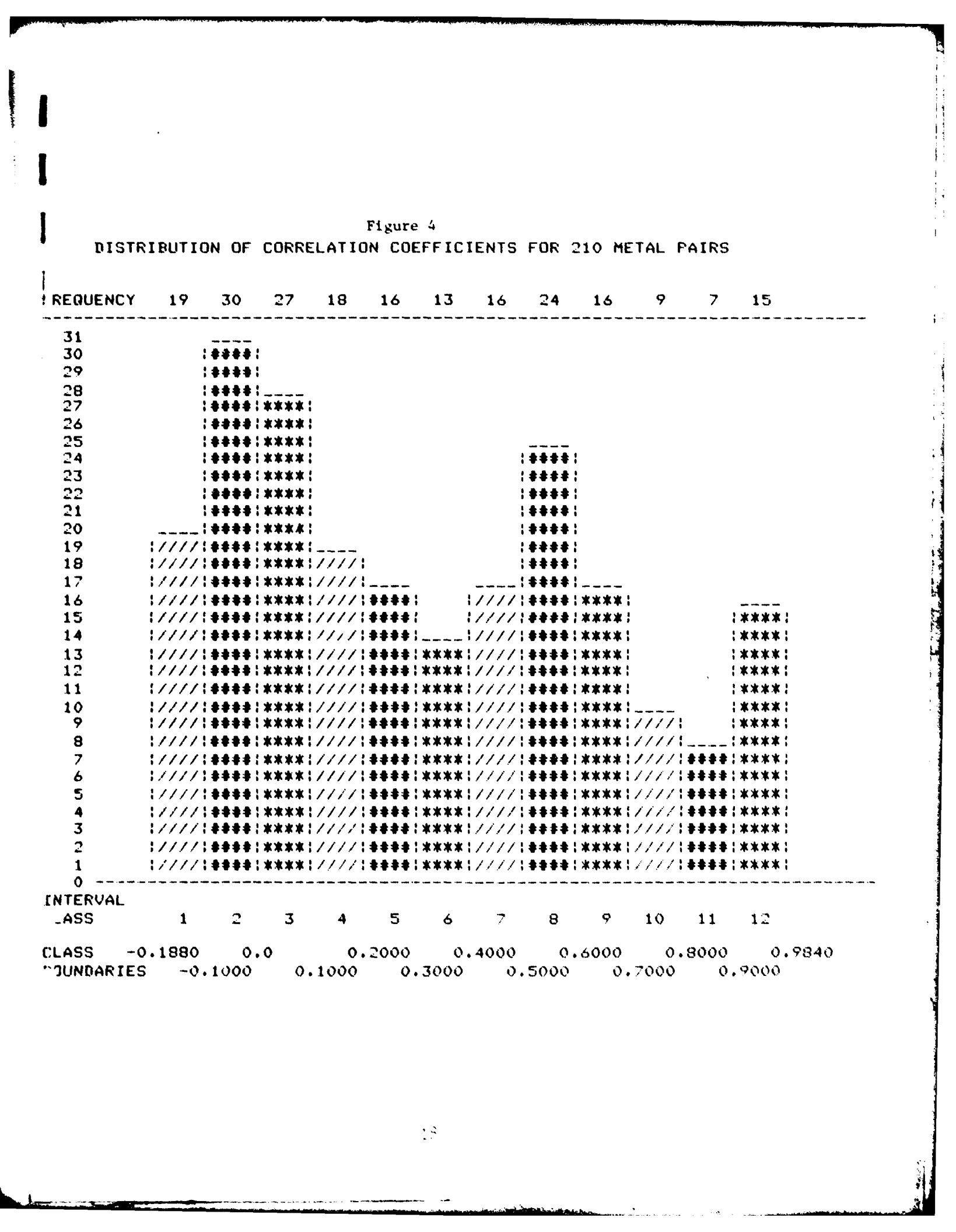
absence of the sulphate anion, barium would thus be removed in solution along with calcium.

(2) Pearson Correlation Coefficients were calculated for all 210 possible pairs of elements. The calculated coefficients fell largely into two general groups: (1) those showing little or no correlation with each other and (2) those showing strong positive correlation. Surprisingly, no pairs of metals were observed to display even moderate negative correlation, and the largest negative value observed was only -0.118. The lack of any significant negative correlation indicates that none of the element pairs examined in this study was increasing at the expense of others and that either the pair increased together or the pair displayed no relationship at all (see Figure 4). The interpretation drawn from these observations is that, once a particular metal is incorporated in the lattices of even the most youthful soil mineral, little in the way of leaching takes place as the soil matures. Because some of the elements are, in fact, soluble in dilute acid solutions, the fact that they do not decrease as the soils mature must indicate that whatever mineral transformations are taking place do not, as some believe, involve the dissolution of the unstable mineral followed by re-precipitation to form a new stable phase (e.g., illite altering to kaolinite). Rather, the change must occur by cation stripping of the unstable mineral followed by structural rearrangement to form the new mineral (see Altschuler, et al, 1963).

(3) Multiple discriminant analyses carried out on grouped samples from the Northwestern Coastal Plain, Northeastern Coastal Plain, Central Hill District and Guatemala indicated, as expected, that the trace element chemistry is a regional phenomenon and for the elements examined in this study, is little affected by climatic variations. All samples from the Yucatan Peninsula contained, essentially, similar quantities of the various trace elements and these, as a group, were different in magnitude from the Guatemalan samples. This is to be expected because sediments of both areas are the result of two different sources, each of which supplied its own, distinctive suite of heavy metals to the depositional basin.

Figure 4

DISTRIBUTION OF CORRELATION COEFFICIENTS FOR 210 METAL PAIRS

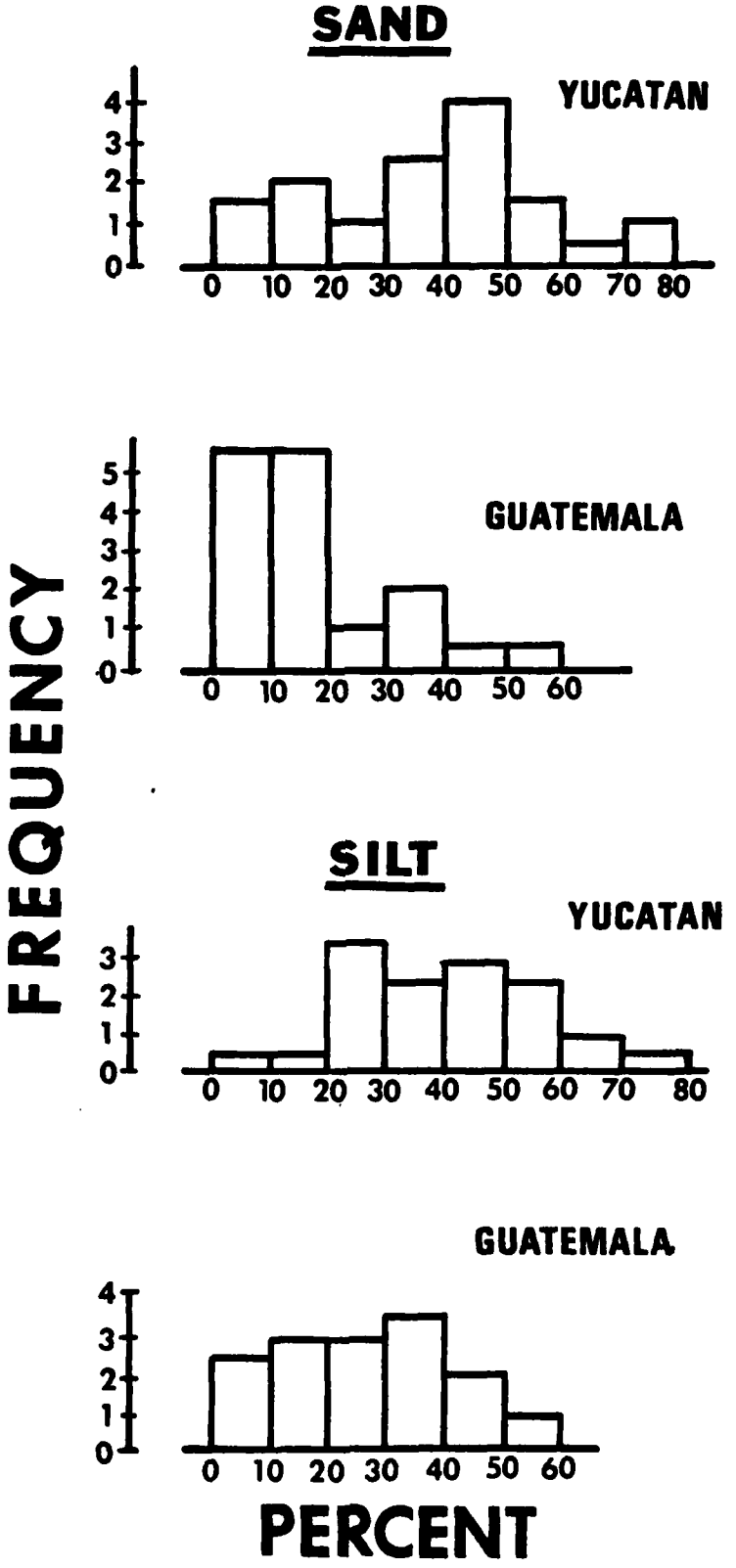


Physical Properties

Size Frequency Distributions.-- Complete size analyses were carried out by sieve and hydrometer methods on 79 samples from Yucatan, Guatemala and the United States. The sand-silt-clay percentage information obtained from these analyses is summarized below:

	Avg. Pct. Sand	Sand Std. Dev.	Avg. Pct. Silt	Silt Std. Dev.	Avg. Pct. Clay	Clay Std.
Yucatan	35.00	20.27	39.82	15.99	25.17	25.49
Guatemala	15.73	13.95	25.60	14.95	58.67	24.48
United States	18.24	21.13	41.43	12.24	40.33	16.58

The textural information from the Yucatan samples was significant and provided important information, not only on one of the more unusual properties of residual limestone soils but also on their origin and development. The Yucatan soils were the only ones examined in this investigation that completely lacked the mineral quartz (evidencing their derivation from "pure" limestones). Numerous insoluble residue analyses carried out by acid leaching bedrock samples disclosed that the chief minerals present in the parent limestones were the clay minerals illite and chlorite. No detrital minerals were observed in the residues (volcanic detritus, heavy minerals, etc.) and all particles were of fine silt-size (less than 10 microns), or smaller. Figure 5 shows a comparison of the variation in percentages of sand-, silt-, and clay-sized constituents for the Yucatan and Guatemala samples (obtained from the size analyses).


SAND
YUCATAN
4
3
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GUATEMALA
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PERCENT

Fig. 5

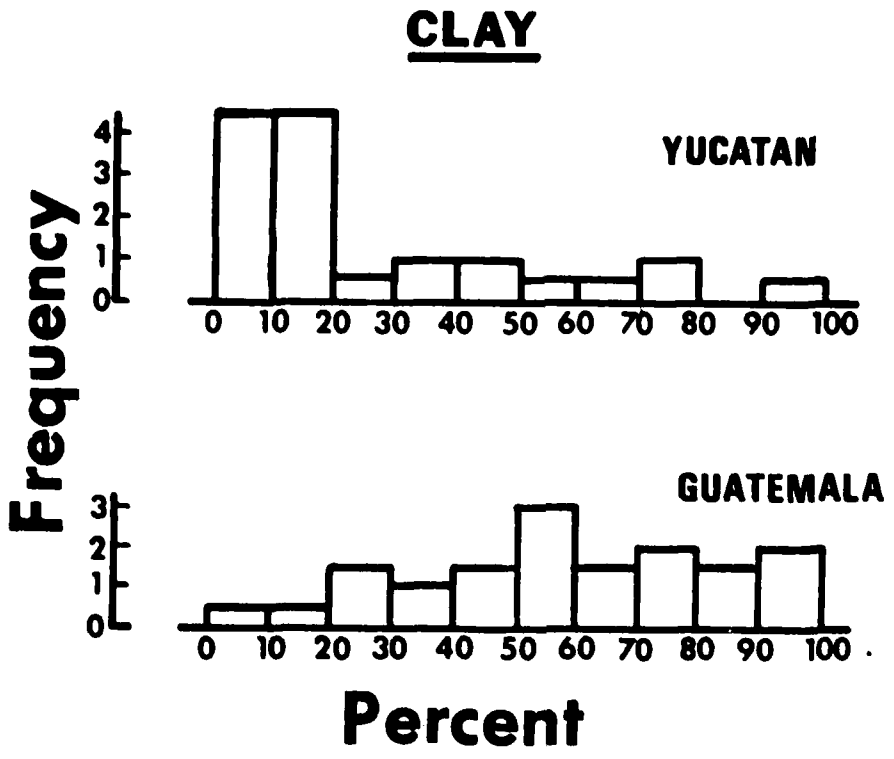

CLAY
YUCATAN
GUATEMALA
Frequency
Percent
0 10 20 30 40 50 60 70 80 90 100
0 1 2 3 4
0 1 2 3

Fig.5, cont.

The Yucatan soils are seen to differ from those from Guatemala in containing significantly higher percentages of sand-sized material and considerably lower percentages of clay-size particles. While sand- and silt-sized particles from Guatemala can be explained by calling upon a detrital origin for the quartz that makes up the fractions, no such origin is possible for the Yucatan "sands". No quartz is present, and the particles consist of various size aggregates of clays and iron oxides that have reached their present size by a complex growth process involving accretion and aggregation of initially fine silt and clay-size grains. This fact is generally overlooked when residual limestone soils are considered but, in the absence of any detrital contribution from parent limestones, no other explanation is possible!

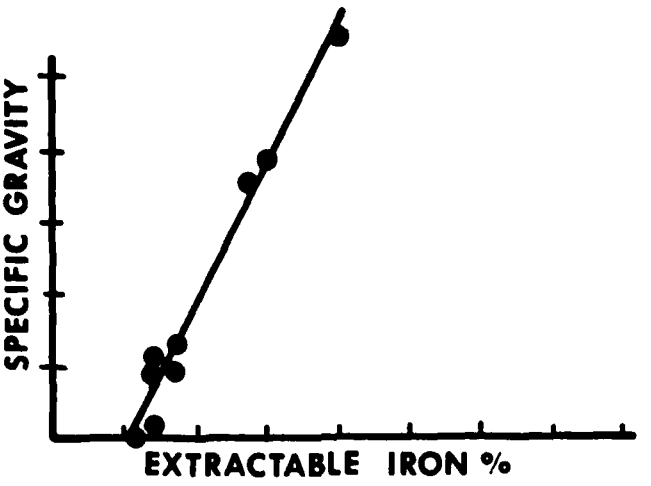
When samples from the Northwestern Coastal Plain, the Northeastern Coastal Plain and the Central Hill District were compared, the more mature soils of the Central Hill District were seen to be richer in clay-size constituents and lower in sand-size particles (see Table 2). Apparently, where the soils are in a youthful stage and little compaction has taken place, larger aggregates develop producing the high sand-size fraction found in the Northwestern and Northeastern Coastal Plains; as accumulation proceeds and the profile thickens, compaction and recrystallization breaks down the mineral aggregates producing the finer textured soils that characterize mature karst terranes.

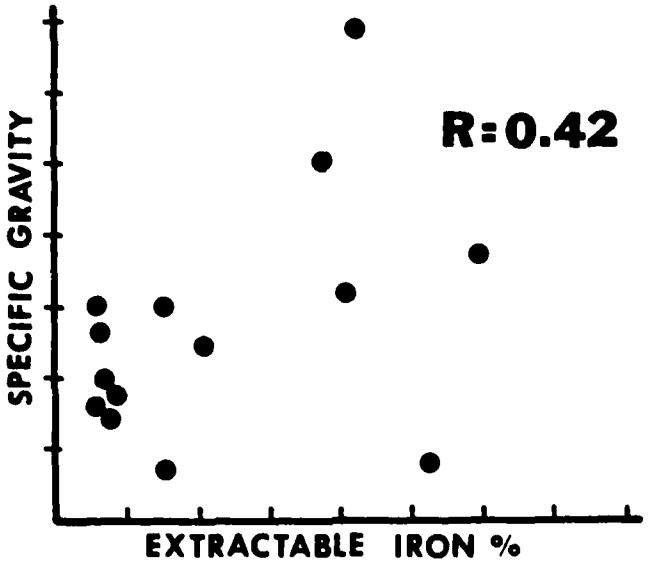
	Pct. Sand	Pct. Silt	Pct. Clay	Mean Dia.*	Sorting Coef.
NW Coastal Plain	32	57	11	5.05	2.05
NE Coastal Plain	44	38	18	5.54	2.90
Central Hill District	26	37	37	7.09	4.30
Guatemala	18	41	40	7.60	4.30

*in phi units

Table 2.-- Variation in textural properties, specific gravity and mean diameter for Yucatan and Guatemalan samples.

Specific Gravity.-- A reconnaissance investigation carried out by Lones and Demeriel (1973) on a limited number of samples from Puerto Rico suggested that the variability observed in the strength properties of soils and clays might be the result of different valence states of iron and the total iron in a given sample. Older soils, they concluded, are more deeply weathered and should possess more iron, which would be reflected in higher specific gravities for the soils, lower void ratios and an increase in the soil's cohesion and shear strength. Using a total of nine samples, they obtained a strong correlation for specific gravity and extractable iron and their results are shown in the top diagram on Figure 6. Using data from 14 residual limestone soils from Yucatan, this investigator attempted to duplicate their results but, as can be seen on the middle diagram, found no such relationship for the Yucatan soils. Attempts to obtain a more linear fit by comparing specific gravity versus: (1) extractable iron as Fe^{+3} and (2) extractable iron as Fe^{+2} were similarly unsuccessful. Some minor


SPECIFIC GRAVITY
EXTRACTABLE IRON %


SPECIFIC GRAVITY
R=0.42
EXTRACTABLE IRON %

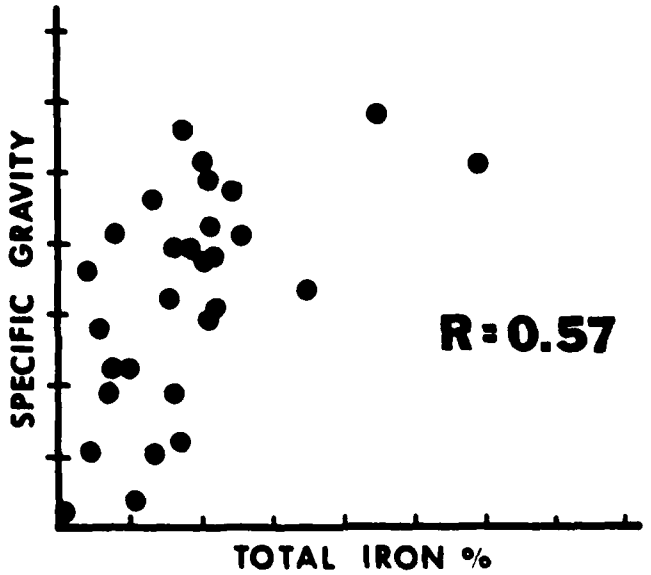

SPECIFIC GRAVITY
R=0.57
TOTAL IRON %

Fig. 6

improvement was obtained when specific gravity was plotted against Total Iron (see bottom diagram, Figure 6) but the fit is far from perfect and the conclusion was reached that no pronounced linear relationship exists for residual limestone soils. Attempts to discover any direct relationships between the percentage of Total Iron, the Atterberg Limits, the Compressive Strength, and the sand-silt-clay content of a sample were similarly un-rewarding and it is most probable that any relationships that do exist are complex and controlled by, as yet, un-identified factors. The correlation matrix for the different variables tested is shown in Table 3.

Atterberg Limits.-- Plastic Limit, Liquid Limit and Plasticity Index were determined for a total of 96 samples from Yucatan, Guatemala and the United States. The summary statistics for data from each of the three regions is given below:

	Avg. Liquid Limit	Std. Dev.	Avg. Plastic Limit	Std. Dev.	Avg. Plasticity Index	Std. Dev.
Yucatan	61.3	15.41	33.6	8.37	27.7	13.44
Guatemala	69.7	13.24	36.9	9.23	32.7	16.32
U. S.	55.9	13.23	20.6	3.95	34.9	12.08

A plot of the Plasticity Index versus Liquid Limit is given in Figure 7 and, with minor exception, samples from the United States are seen to plot above the "A" line and those from Yucatan fall below the line. Soils from Guatemala

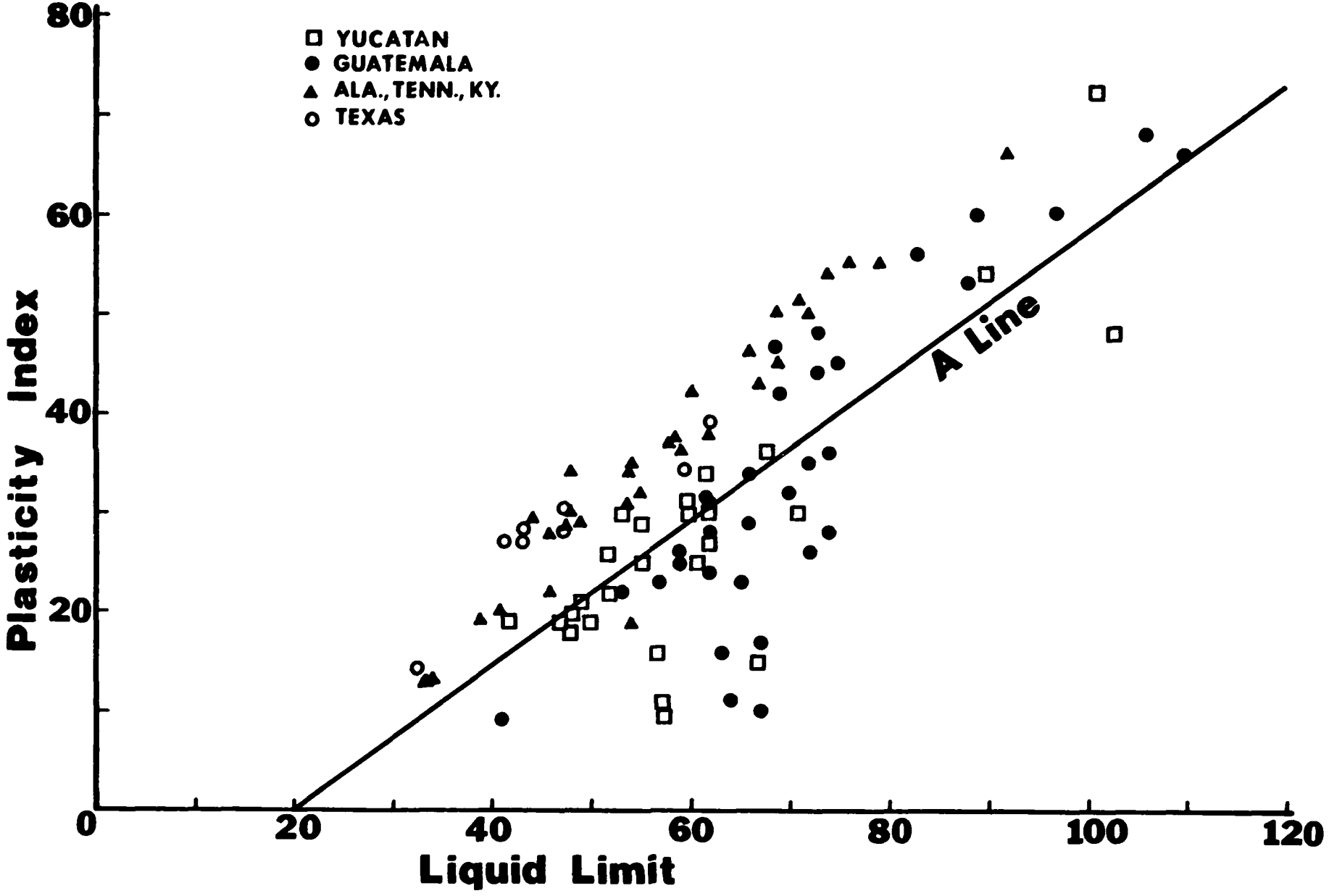

YUCATAN
GUATEMALA
ALA., TENN., KY.
TEXAS
A Line
Plasticity Index
Liquid Limit
0
20
40
60
80
100
120

Fig. 7

	Compressive Strength	Density	Pct. Iron	Pct. Sand	Pct. Silt	Pct. Clay	Liquid Limit	Plastic Limit	Plasticity Index
Compressive Strength	1.00	-0.054	-0.262	-0.187	0.250	-0.061	-0.131	0.094	-0.298
Density		1.00	0.357	-0.589	-0.097	0.498	-0.825	-0.791	-0.507
Pct. Iron			1.00	-0.145	0.164	-0.031	-0.593	-0.713	-0.242
Pct. Sand				1.00	-0.132	-0.572	0.442	0.276	0.413
Pct. Silt					1.00	-0.722	-0.323	0.170	-0.670
Pct. Clay						1.00	-0.078	-0.375	0.248
Liquid Limit							1.00	0.778	0.798
Plastic Limit								1.00	0.243
Plasticity Index									1.00

Table 3.-- Pearson correlation coefficients for physical property data from residual limestone soils and clays.

are characterized by high Plastic Indices and fall in both fields. The most striking difference between Temperate and Tropical clays was observed for values of the Plastic Limit and histograms comparing values of this variable for the two climatic areas are presented in Figure 8. The reason for the marked difference seen must, in some way, reflect the greater amount of kaolinite and lesser illite, as well as the higher amounts of iron and alumina, and lower silica which characterize Tropical clays. Though a direct relationship is known to exist between the amount of clay-size sediments present in a sample and its Limits, two samples having the same size frequency distribution will often have markedly different Atterberg Limits. Because a considerable amount of data had been collected on samples for which the Limits were also calculated, it was decided to carry out a multiple regression analysis on the data in order to determine which of the variables exerted the greatest control of the three indices.

In a multiple regression analysis, one variable is chosen as the dependent variable (in this case each Atterberg Limit was set as "Y") and the remaining variables are set as independent variables, which are believed to "control" Y (X_1, X_2, X_3, etc.).

$$\underset{\text{(Dependent Variable)}}{Y} = a_1X_1 + a_2X_2 + a_3X_3 + \ldots\ldots + a_nX_n$$

A mathematical analysis of the data matrix is then carried out to solve for the regression coefficients (a_1, a_2, a_3, etc.)

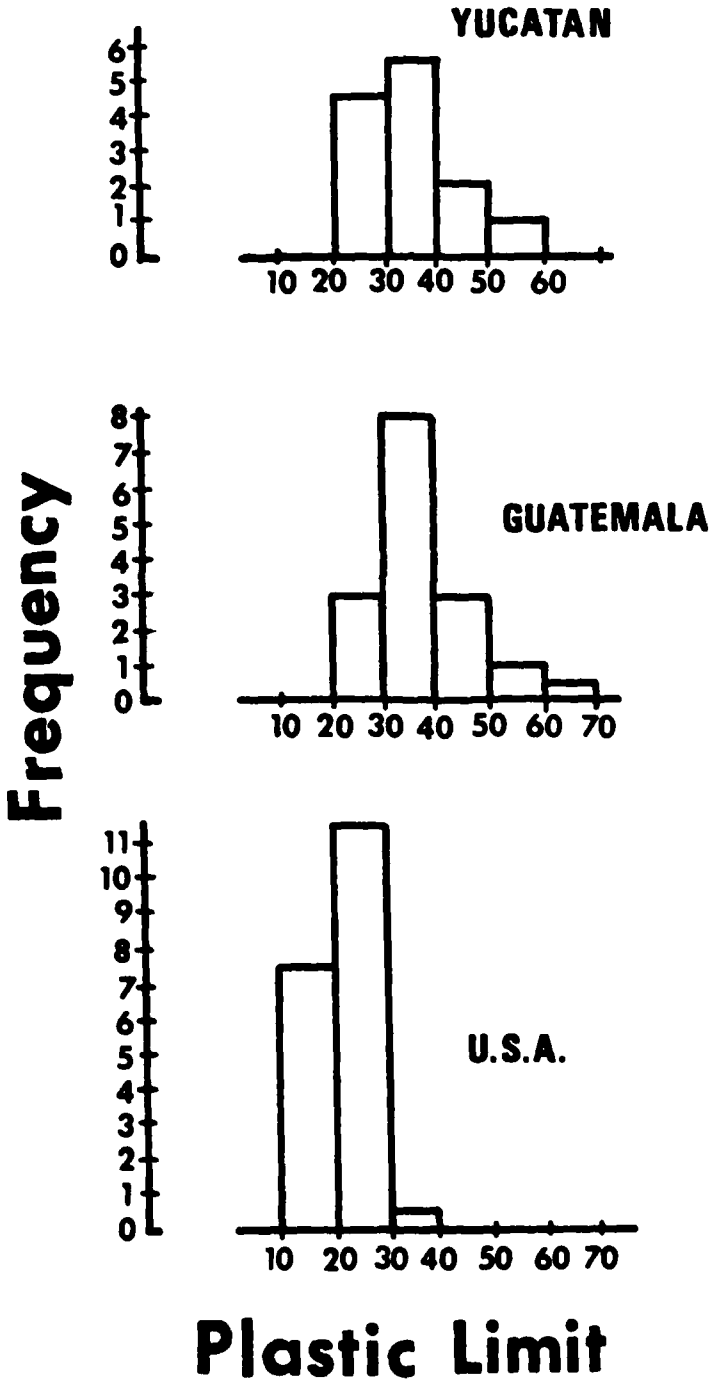

YUCATAN
GUATEMALA
U.S.A.
Frequency
Plastic Limit
0 1 2 3 4 5 6
0 1 2 3 4 5 6 7 8
0 1 2 3 4 5 6 7 8 9 10 11
10 20 30 40 50 60
10 20 30 40 50 60 70
10 20 30 40 50 60 70

Fig. 8

which allow a predictive equation to be derived. A "stepwise" multiple regression analysis was used in order to identify those variables that were adjudged statistically significant in explaining the variability of each of the Limits and to exclude those whose contribution was statistically negligible. The results of the analyses for the 79 samples are shown in Table 4. Each Atterberg Limit was set as the dependent variable "Y" and the matrix analyzed to find which combinations of variables from those listed below best explained the variance of the data matrix:

1- Percent SiO_2
2- Percent Al_2O_3
3- Percent Fe_2O_3
4- Percent MgO
5- Percent CaO
6- Percent Na_2O
7- Percent K_2O
8- Percent H_2O
9- Specific Gravity
10- Percent Sand
11- Percent Silt
12- Percent Clay
13- Percent extractable iron/percent total iron
14- Percent extractable iron (as Fe^{+2})/total iron
15- Percent extractable iron (as Fe^{+3})/total iron
16- Percent extractable iron (as Fe^{+2})/total sample weight
17- Percent extractable iron (as Fe^{+3})/total sample weight

The success of each predictive equation can be assessed by: (1) the size of the Standard Error (a plus or minus value associated with the calculated value of the dependent variable), (2) the computed F statistic (if the computed value exceeds the tabulated F value, the equation is judged to have statistical significance at a given confidence level) and (3) the R^2 value (this statistic measures the total amount

REGRESSION EQUATION

$$\underset{\text{Dependent Variable}}{Y} = a_1X_1 + a_2X_2 + a_3X_3 \ldots\ldots + a_nX_n$$

Y = Liquid Limit		Y = Plastic Limit	
Variable	Standardized Regression Coefficient	Variable	Standardized Regression Coefficient
Pct. K_2O	$a_1 = -0.14$	Pct. SiO_2	$a_1 = -0.75$
Pct. Ext. Fe/Tot. Fe	$a_2 = -0.28$	Ext. Fe/Tot. Wt.	$a_2 = 0.57$
Pct. Clay	$a_3 = 0.52$	Pct. Silt	$a_3 = 0.47$
Pct. SiO_2	$a_4 = -0.52$	Pct. Ext. Fe^{+2}/Tot. Ext. Fe	$a_4 = 0.59$
Density	$a_5 = -0.33$	Pct. Clay	$a_5 = 0.15$
Pct. CaO	$a_6 = -0.43$	Pct. MgO	$a_6 = -0.28$
Pct. Al_2O_3	$a_7 = -0.46$	Density	$a_7 = -0.32$
Pct. Ext. Fe^{+2}/Tot. Fe	$a_8 = -0.50$	Pct. K_2O	$a_8 = 0.03$
Pct. Ext. Fe^{+2}/Tot. Ext. Fe	$a_9 = 0.08$	Pct. Ext. Fe^{+2}/Tot. Ext. Fe	$a_9 = -1.08$
Pct. Na_2O	$a_{10} = -0.16$	Pct. Na_2O	$a_{10} = -0.13$
Pct. MgO	$a_{11} = -0.23$	Tot. Fe %	$a_{11} = -1.12$
Pct. Silt	$a_{12} = -0.09$	Ext. Fe^{+2}/Tot. Spl. Wt.	$a_{12} = 1.14$
Ext. Fe^{+3}/Tot. Spl. Wt.	$a_{13} = 0.37$	Pct. Al_2O_3	$a_{13} = 0.16$
Ext. Fe^{+2}/Tot. Spl. Wt.	$a_{14} = -0.31$	Pct. CaO	$a_{14} = -0.11$
		Tot. Ext. Fe %	$a_{15} = -0.33$
Std. Error	9.21	Std. Error	5.02
Tabulated F Statistic	2.69	Tabulated F Statistic	2.72
Computed F Statistic	4.47	Computed F Statistic	5.88
R^2	0.84	R^2	0.76

Table 4.— Results of multiple regression analysis for Atteberg Limit data.

Continuation of Table 4 (Regression Equation)

Y = Plasticity Index

Variable	Standardized Regression Coefficient
Pct. Clay	$a_1 = 0.89$
Density	$a_2 = -0.11$
Pct. K_2O	$a_3 = -0.14$
Pct. CaO	$a_4 = -0.39$
Pct. Al_2O_3	$a_5 = -0.67$
Pct. SiO_2	$a_6 = -0.07$
Pct. Na_2O	$a_7 = -0.07$
Tot. Fe %	$a_8 = 0.98$
Pct. Ext. Fe^{+2}/Tot. Fe	$a_9 = 1.46$
Ext. Fe^{+2}/Tot. Spl. Wt.	$a_{10} = -1.47$
Pct. Ext. Fe^{+2}/Tot. Ext. Fe	$a_{11} = -0.51$
Pct. Sand	$a_{12} = 0.36$
Pct. MgO	$a_{13} = -0.07$

Std. Error	8.61
Tabulated F Statistic	2.60
Computed F Statistic	4.44
R^2	0.82

of variance in calculating values of the dependent variable that is explained by the different independent variables used in the equation. For the data used in this study, each of the regression equations possessed high R^2 values, indicating that the variables used to account for most of the variance of the data matrix (Liquid Limit, 84%; Plastic Limit, 76% and Plasticity Index, 82%). Further, the computed F-statistic does, in all three cases, exceed the value found in standard F tables, indicating that the equations have statistical significance. A rule of thumb, however, used by statisticians is that the computed value should exceed the tabulated value by four times in order for the equation to be used as a reliable predictor. None of the equations meets this criteria hence, though the data may be statistically significant, it falls short of providing a truly reliable predictor. The Standard Error associated with each of the equations would be rated as "good" for the Plastic Limit ($\pm$ 5.02) and "fair to good" for the Plasticity Index and Liquid Limit.

An additional interpretation that can be drawn from the data in Table 4 is the importance of each variable with respect to the individual Atterberg Limits. The magnitude of the standardized regression coefficient, regardless of sign, provides this information directly. For example, in the case of the Liquid Limit, the largest regression coefficients are those associated with "percentage of clay" and "percentage of silica" (both 0.52). The "signs" preceding each coefficient explain how the variable changes

with respect to the dependent variable (the particular Atterberg Limit). In the case of the Liquid Limit, an increase in the percent clay is associated with an increase in the Liquid Limit. Similarly, as the silica content of the samples decreases, the Liquid Limit rises. This relationship is known to exist and montmorillonitic clays generally possess higher Liquid Limits than do kaolinitic clays. The former average nearly 50 percent silica, by weight, whereas kaolinites average approximately 40 percent. Less easily interpreted is the observation that the ratio of the "percent of extractable iron (as Fe^{+3})/total iron" is only slightly less important. Apparently, the amount of iron in a sample and its valence state do exert some complex, as yet un-explained control, over the strength properties of soils and clays.

The conclusion drawn from this phase of the study is that the Atterberg Limits are complexly controlled measures of the strength properties of clays that are influenced by a number of different variables. Each of the Limits is apparently controlled by different combinations of chemical and physical properties but, on the whole, the amount of iron in the divalent and trivalent states does affect the magnitude of each Limit. The fact that none of the R^2 values approaches 100 percent, however, indicates that other phenomena must also influence their magnitude and, as before, a total explanation of their origin remains elusive.

SUMMARY

The study carried out on soils formed by the weathering of limestones has provided a great deal of previously lacking "baseline" information on these materials and has shown their uniqueness among soil communities. Further, it has shown that although the same variables that act to break down other rock types also act upon limestones, the order of importance is not necessarily the same. Regional relief acts to control profile development, mineralogy and chemistry of these soils in a manner not observed for other rock types. Chemical and mineralogical analyses carried out on the residual clays revealed that their development and transformations are strongly affected, and dependent on, the climatic zone in which they form and on the particular stage of geomorphic development of the karst terrane. Similar climatic controls were also observed for some of the geotechnical properties, specifically the Atterberg Limits. The latter were found to be measures complexly related to a number of different variables and impossible to accurately predict in the absence of detailed multivariate analysis.

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APPENDIX I

LIST OF PAPERS PRESENTED AND PUBLICATIONS TO DATE RESULTING FROM THIS INVESTIGATION

1. Isphording, Wayne C. (1977): Tropical weathering, a systematic, quantitative approach. Abs., Southeastern Section meeting, Geol. Soc. America, Winston-Salem, N. C., p. 150-151.

2. Isphording, Wayne C. (1977): R-Q Mode Factor Analysis of Tropical Soils. Abs., Joint Conference, Clay Minerals Society and International Commission for Study of Bauxites, Alumina, and Aluminum, Kingston, Jamaica, p. 36.

3.-4. Isphording, Wayne C. (1978): Mineralogical and physical properties of Gulf Coast limestone soils. Transactions, Gulf Coast Association of Geological Societies, v. 28, p. 210-214. Also presented as invited paper at annual meeting, New Orleans, La. (October, 1978).

5. Isphording, Wayne C., Steerman, Patrick and Young, Roger (1979): Chemical, mineralogical and geotechnical properties of residual limestone soils. Abs., Southeastern Section meeting, Geol. Soc. America, Blacksburg, Va., p. 183.

6.-7. Isphording, Wayne C. (1979): Chemical differentiation of Temperate and Tropical limestone clays. Transactions, Gulf Coast Association of Geological Societies, v. 29, p. 252-256. Also presented as invited paper at annual meeting, San Antonio, Texas (October, 1979).

8. Isphording, Wayne C., Kibler, Elizabeth and Steerman, Patrick (1979): Effect of Iron (II):Iron (III) ratios on the engineering properties of Central American residual soils. Abs., Annual meeting, Alabama Academy of Sciences, Huntsville, Ala., p. 12.

9. Isphording, Wayne C., (1980): A multivariate approach to the chemical and mineralogical differentiation of residual tropical clays. Submitted for presentation at annual meeting, American Association of Petroleum Geologists, Denver, Colorado.

10. Isphording, Wayne C. and Kibler, Jon (1980): Sedimentary normative analysis, an empirical approach. Manuscript to be submitted for publication in Jour. Sedim. Petrol., January, 1980.

APPENDIX II

MAJOR OXIDE ANALYSIS DATA MATRIX FOR YUCATAN, GUATEMALA, "OTHER" TROPICAL LOCATIONS AND THE UNITED STATES

Sample	Location and Reference
1 - 3	Bahamas: Ahmad and Jones (1969)
4 - 11	Guam: Carroll and Hathaway (1963)
12 - 15	Java: Van Baren (1928)
16 - 22	Brazil: Clemency (1977)
23 - 27	Barbados
28 - 29	Honduras: Bennett (1926)
30 - 31	Canal Zone: Bennett (1926)
32 - 33	Republic of Panama: Bennett (1926)
34 - 42	Cuba: Bennett and Allison (1928)
43 - 51	Puerto Rico: Roberts (1936)
52	Mexico (Chiapas): Isphording, this study
53 - 58	Guatemala: Cowgill and Hutchinson (1963)
59 - 75	Guatemala: Isphording, this study
76 - 102	Yucatan: Isphording, this study
103 - 104	Holland: Jenny (1941)
105 - 112	Palestine, Cyprus: Reifenberg and Whittles (1948)
113 - 115, 119, 121, 123, 125, 126	Texas: Isphording, this study
116, 117, 122, 124, 127	Missouri: Isphording, this study
118	Alabama: Isphording, this study
120	Tennessee: Isphoridng, this study
128, 129	Kentucky

NOTE: all analyses are given in percent

SAMPLE	SILICA	ALUMINA	IRON	MAGNESIA	LIME	SODIUM	POTASH	WATER
1.00	18.90	40.90	15.60	0.62	0.31	0.29	0.72	19.70
2.00	20.40	44.00	15.50	0.66	0.95	0.45	0.71	16.50
3.00	19.90	43.20	16.90	0.69	0.14	0.26	0.64	16.20
4.00	1.20	41.10	22.60	0.74	0.40	0.03	0.08	29.40
5.00	1.10	42.60	22.10	1.20	0.31	0.03	0.09	24.60
6.00	1.00	40.00	21.00	0.16	0.41	0.06	0.07	27.00
7.00	2.30	38.50	19.40	0.50	2.00	0.06	0.14	25.00
8.00	26.80	24.80	19.00	0.54	0.62	0.06	0.10	25.00
9.00	33.00	29.00	16.20	0.66	0.25	0.07	0.08	19.74
10.00	34.20	30.40	14.60	0.66	0.21	0.08	0.08	18.77
11.00	34.40	29.70	14.60	0.71	0.36	0.08	0.10	19.05
12.00	40.39	22.53	12.59	1.35	1.82	0.15	0.07	19.92
13.00	41.67	27.39	9.38	1.40	1.60	0.45	0.24	17.02
14.00	44.51	18.56	14.95	1.49	2.16	0.15	0.07	17.07
15.00	36.37	4.12	2.90	0.75	29.49	0.80	0.40	21.83
16.00	59.20	20.13	8.56	0.34	0.10	0.03	1.06	7.35
17.00	64.10	18.56	7.48	0.35	0.11	0.03	1.02	6.42
18.00	47.30	28.08	10.89	0.37	0.20	0.03	1.17	9.62
19.00	58.00	22.19	7.93	0.33	0.12	0.06	1.57	7.47
20.00	63.70	17.37	8.21	0.48	0.09	0.05	1.90	5.45
21.00	60.60	17.86	8.61	1.12	0.22	0.07	2.30	5.64
22.00	59.70	16.51	7.45	3.25	2.37	0.88	3.29	4.12
23.00	48.76	23.98	13.73	0.12	0.08	0.61	0.36	7.60
24.00	43.10	19.23	12.18	0.72	1.78	0.38	0.57	12.00
25.00	37.45	15.73	11.57	0.50	1.51	0.54	0.42	10.49
26.00	36.59	23.02	12.77	0.35	2.50	0.32	0.26	11.66
27.00	29.33	27.55	11.69	0.69	3.83	0.15	0.44	10.96
28.00	57.59	17.26	5.77	0.70	0.74	0.41	1.89	13.57
29.00	62.06	18.80	5.95	0.65	0.45	0.43	1.75	8.57
30.00	58.35	13.67	12.37	0.51	0.62	0.36	0.28	12.31
31.00	49.50	22.59	12.56	0.92	2.41	0.26	0.32	10.17
32.00	47.48	17.04	10.67	1.97	1.98	0.13	0.32	19.30
33.00	49.49	19.25	11.85	2.23	1.93	0.11	0.28	13.78
34.00	25.14	26.48	26.77	0.32	0.93	1.55	0.41	17.80
35.00	24.45	25.43	28.64	0.39	4.64	1.54	0.31	12.88
36.00	46.23	23.77	8.66	0.19	0.93	0.46	2.00	16.10
37.00	43.66	29.03	12.43	0.13	0.61	0.37	1.80	12.00
38.00	43.58	29.69	11.06	0.14	0.45	0.37	1.72	12.15
39.00	43.63	31.08	10.21	0.34	0.50	0.49	0.40	12.28
40.00	36.21	27.16	15.13	0.23	0.51	0.38	0.31	17.79
41.00	38.67	29.92	14.70	0.26	0.43	1.59	0.41	14.02
42.00	39.23	31.10	14.12	0.42	0.31	1.58	0.43	12.12
43.00	37.20	28.79	17.34	0.52	0.25	0.02	0.23	15.03
44.00	36.46	29.21	19.46	0.44	0.18	0.05	0.16	13.45
45.00	36.24	30.84	18.48	0.41	0.23	0.12	0.23	12.88
46.00	35.98	30.76	19.20	0.51	0.10	0.10	0.21	12.28
47.00	35.25	30.91	19.73	0.46	0.18	0.10	0.21	12.51
48.00	47.52	21.53	14.39	0.36	0.23	0.05	0.18	17.53
49.00	45.24	24.48	15.97	0.38	0.18	0.03	0.15	15.19
50.00	38.36	27.91	18.65	0.33	0.24	0.01	0.23	14.56
51.00	38.26	27.58	19.37	0.34	0.12	0.04	0.19	14.61
52.00	49.04	26.91	13.17	0.29	0.01	0.07	0.16	11.00

SAMPLE	SILICA	ALUMINA	IRON	MAGNESIA	LIME	SODIUM	POTASH	WATER
53.00	59.00	20.00	5.50	1.00	1.60	0.40	0.18	23.00
54.00	64.00	22.00	6.50	1.10	1.70	0.32	0.08	25.00
55.00	60.00	23.00	6.50	0.80	1.50	0.20	0.09	22.00
56.00	60.00	24.00	6.00	1.50	3.20	0.12	0.10	22.00
57.00	62.00	24.00	6.00	1.80	2.10	0.15	0.09	27.00
58.00	59.00	26.00	6.00	2.10	2.00	0.15	0.09	25.00
59.00	47.99	15.39	4.89	1.13	2.64	0.06	0.07	22.67
60.00	30.59	34.07	11.70	0.29	0.46	0.07	0.26	20.53
61.00	38.37	32.08	7.24	0.24	0.53	0.04	0.02	17.07
62.00	42.60	18.05	5.26	1.34	1.55	0.12	0.03	21.85
63.00	55.68	22.76	5.11	1.22	0.33	0.17	4.57	9.62
64.00	45.49	26.84	7.37	0.18	0.04	0.21	0.01	16.50
65.00	42.81	29.86	11.93	0.43	0.00	0.04	0.29	13.69
66.00	55.68	22.76	5.73	1.11	0.33	0.17	4.39	8.83
67.00	43.87	26.85	10.93	0.59	0.01	0.05	0.57	12.54
68.00	47.73	26.92	17.13	0.20	0.00	0.05	0.05	7.61
69.00	17.96	44.87	9.20	0.36	0.03	0.16	0.14	25.55
70.00	43.55	28.30	5.13	0.23	0.66	0.00	0.02	21.95
71.00	33.09	13.89	4.60	1.04	17.70	0.23	0.21	28.30
72.00	35.61	27.43	10.37	0.57	0.56	0.08	0.54	23.84
73.00	44.49	25.26	5.84	0.21	0.63	0.04	0.01	16.90
74.00	42.35	30.56	7.58	0.26	0.55	0.05	0.03	17.50
75.00	39.84	25.69	8.40	0.39	1.15	0.04	0.02	20.83

SAMPLE	SILICA	ALUMINA	IRON	MAGNESIA	LIME	SODIUM	POTASH	WATER
76.00	35.40	27.04	6.93	0.51	2.42	0.08	0.61	21.77
77.00	37.48	33.10	6.29	0.96	0.96	0.07	1.98	18.68
78.00	30.53	27.00	8.41	0.91	2.88	0.08	0.49	28.70
79.00	29.32	28.08	8.04	0.92	2.15	0.06	1.14	24.50
80.00	18.85	16.79	5.65	0.17	12.41	0.13	1.15	37.50
81.00	22.31	16.61	5.24	0.95	12.30	0.13	1.02	35.97
82.00	44.80	18.10	5.91	1.96	1.89	0.11	0.31	21.79
83.00	37.38	26.38	8.10	0.39	1.94	0.26	0.90	23.32
84.00	41.78	26.95	6.51	0.38	2.54	0.15	0.49	17.85
85.00	39.46	27.16	7.36	0.30	1.00	0.08	0.35	25.84
86.00	30.91	31.64	11.02	0.28	0.26	0.15	0.46	23.76
87.00	33.90	25.98	7.98	0.74	2.18	0.22	0.43	26.75
88.00	26.83	22.22	11.58	1.15	3.06	0.29	0.42	32.53
89.00	30.39	34.21	10.15	1.42	0.79	0.87	0.97	20.76
90.00	39.61	31.61	8.07	0.79	0.83	0.29	0.60	16.51
91.00	45.49	26.84	7.37	0.18	0.04	0.21	0.00	16.50
92.00	40.74	13.84	4.39	2.24	1.04	0.43	0.21	24.28
93.00	46.56	19.63	5.35	2.11	0.49	0.13	1.60	21.54
94.00	38.00	28.75	8.61	1.01	0.18	0.09	0.63	25.76
95.00	38.40	30.18	8.04	0.95	0.22	0.08	0.66	20.47
96.00	41.51	32.13	7.15	1.75	0.17	0.10	1.67	14.89
97.00	40.90	32.34	8.96	0.74	0.10	0.08	1.08	19.15
98.00	28.46	29.89	6.94	0.89	0.10	0.12	1.57	31.03
99.00	26.83	22.22	11.58	1.15	3.06	0.05	0.54	32.53
100.00	32.47	26.45	6.57	0.49	3.09	0.11	0.68	21.77
101.00	34.59	33.91	8.00	0.76	1.05	0.11	1.13	11.26
102.00	33.93	29.56	8.40	0.90	1.56	0.06	0.51	22.81

SAMPLE	SILICA	ALUMINA	IRON	MAGNESIA	LIME	SODIUM	POTASH	WATER
103.00	73.38	7.59	2.63	0.38	1.01	0.55	1.38	6.05
104.00	65.73	8.57	6.37	1.12	3.39	0.42	1.43	9.18
105.00	26.58	2.81	7.59	3.86	31.80	0.42	0.71	22.54
106.00	66.70	0.64	4.33	1.61	14.15	0.11	0.21	12.25
107.00	73.75	1.05	1.45	0.16	14.20	0.01	0.01	9.37
108.00	51.07	12.29	7.99	2.27	6.60	0.47	0.79	17.87
109.00	50.39	16.50	9.28	0.75	3.39	2.91	0.81	14.64
110.00	48.08	14.94	8.19	1.38	6.35	2.16	1.08	14.33
111.00	45.81	13.80	11.85	5.00	11.35	1.77	1.51	10.00
112.00	49.93	16.67	11.40	1.13	4.00	0.68	0.78	16.77
113.00	52.38	9.65	4.70	1.08	10.15	0.20	1.10	19.74
114.00	25.29	5.81	2.35	0.96	29.79	0.08	0.94	33.78
115.00	57.06	9.55	23.60	1.03	7.40	0.16	1.04	19.16
116.00	67.36	13.38	5.93	1.74	0.96	0.18	1.17	8.28
117.00	60.52	16.89	5.76	1.45	0.61	0.02	1.69	12.06
118.00	68.78	19.96	7.22	0.49	0.01	0.05	1.00	2.49
119.00	44.83	10.92	3.70	1.13	0.97	0.08	1.86	36.51
120.00	81.65	12.76	5.07	0.29	0.02	0.06	0.86	4.00
121.00	72.13	9.60	3.33	0.98	0.67	0.16	1.38	19.01
122.00	60.38	13.01	4.87	1.14	0.98	0.42	1.54	18.87
123.00	44.88	11.20	3.56	1.17	1.24	0.19	1.55	34.50
124.00	75.04	10.41	3.81	0.99	0.01	0.49	1.63	6.62
125.00	48.03	10.42	3.64	1.10	1.29	0.19	1.75	32.58
126.00	62.37	9.81	3.13	1.05	0.83	0.14	1.36	20.31
127.00	50.85	12.87	4.47	4.57	0.78	0.08	1.56	16.02
128.00	29.14	4.73	2.91	1.15	32.60	1.46	2.00	26.01
129.00	39.05	12.11	10.40	4.39	18.74	1.33	1.50	12.48

APPENDIX III

TRACE ELEMENT ANALYSIS DATA MATRIX FOR YUCATAN-GUATEMALA SAMPLES

Sample	Location
1 - 16	Northwestern Coastal Plain (Yucatan)
17 - 34	Northeastern Coastal Plain (Yucatan)
35 - 46	Central Hill District (Yucatan)
47 - 52	Montmorillonite clays from Block Fault Basins west of Chetumal (Yucatan)
53 - 79	Northern Guatemala (Peten District)

NOTE: Sodium, Potassium, and Iron values are in percent; all others are in parts per million.

Where values for a particular element were not calculated, the mean value has been inserted.

SAMPLE LOCATIONS FOR TRACE ELEMENT ANALYSIS

NORTHWESTERN COASTAL PLAIN

1 10 KILOMETERS EAST OF MERIDA; 2 KILOMETERS EAST OF CHOLUL SURFACE SAMPLE IN OLD FIELD
2 40 KILOMETERS WEST OF CHICHEN ITZA IN NEWLY CLEARED FIELD; SURFACE SAMPLE.
3 DEPRESSION ON SIDE OF MAIN HIGHWAY, 14 KILOMETERS NORTH OF CAMPECHE. DEPTH: 14" - 24"
4 SAMPLE FROM EXPOSED SOIL IN SLIGHT DEPRESSIONS AT MAYAPAN
5 8 KILOMETERS SOUTH OF UMAN. DEPRESSION ON SIDE OF ROAD, 0"-8"
6 CULTIVATED FIELD, 5 KILOMETERS SOUTH OF TEMAX, 0" - 3"
7 "PROTOSOIL". 2 KILOMETERS NORTH OF TELCHAK, SMALL DEPRESSION ON SIDE
8 YOUTHFUL SOIL EXPOSED IN SMALL DEPRESSION, 30 KILOMETERS SOUTHEAST OF KINCHIL (SW OF MERIDA), 0" - 2"
9 SURFACE SAMPLE, 8 KILOMETERS SOUTH OF DZILAM DE BRAVO. MAXIMUM SOIL THICKNESS IS 3".
10 "PROTOSOIL", 18 KILOMETERS SOUTHEAST OF KINCHIL, 0" - 1"
11 CULTIVATED FIELD, 1 KILOMETER SOUTH OF CALKANI (SOUTH OF MAXCANU), 0" - 6".
12 OLD FIELD 2 KILOMETERS SOUTH OF HECELCHAKAN, 0" - 12".
13 SAMPLE FROM WATER-FILLED AGUADA 6 KILOMETERS NORTH OF MUNA
14 OLD FIELD 3 KILOMETERS SOUTH OF PYRAMID AT IZAMAL, 0" - 3".
15 OLD FIELD, 50 KILOMETERS WEST OF CHICHEN ITZA ON NORTH SIDE OF HW 180, 0" - 3".
16 CULTIVATED FIELD, 14 KILOMETERS SOUTH OF IZAMAL, 0" - 12"

NORTHEASTERN COASTAL PLAIN

17 SURFACE SAMPLE, OLD FIELD ONE-HALF KILOMETER NORTH OF VALLADOLID.
18 SURFACE SAMPLE FROM CULTIVATED FIELD ON EAST SIDE OF ROAD, 9 KILOMETERS SOUTH OF RIO LAGARTOS
19 SURFACE SAMPLE FROM OLD FIELD, EAST SIDE OF ROAD, 4 KILOMETERS SOUTH OF RIO LAGARTOS
20 EAST SIDE OF VALLADOLID-RIO LAGARTOS HIGHWAY, 10 KILOMETERS NORTH OF VALLADOLID, 0" - 12".
21 WEST SIDE OF VALLADOLID-RIO LAGARTOS HIGHWAY, 22 KILOMETERS NORTH OF VALLODOLID, 0" - 6".
22 CULTIVATED FIELD, 1 KILOMETER EAST OF PETO, 0" - 8"
23 CULTIVATED FIELD, 20 KILOMETERS WEST OF CHICHEN ITZA, MAIN HIGHWAY, 0" - 3".
24 3 KILOMETERS NW OF KILOMETER 50 ON PETO-FELIPE CARILLO PUERTO HIGHWAY, CLEARED FIELD, SURFACE SAMPLE.
25 16 KILOMETERS SOUTH OF TULUUM, ON FELIPE CARILLO PUERTO-TULUUM HIGHWAY, 0" - 2".
26 15 KILOMETERS NORTH OF FELIPE CARILLO PUERTO, OLD FIELD, 0" - 7 ".
27 31 KILOMETERS NORTH OF FELIPE CARILLO PUERTO, SURFACE SAMPLE FROM OLD FIELD. MAXIMUM SOIL THICKNESS 4" - 6".
28 OLD FIELD, 16 KILOMETERS SE OF KILOMETER 50 ON PETO-FELIPE CARILLO PUERTO HIGHWAY, 0" - 12".
29 15 KILOMETERS EAST OF VALLADOLID ON ROAD TO CHEMAX, 0" 4".
30 OLD FIELD, 5 KILOMETERS SOUTHEAST OF OXKUTZCAB, 0" - 12" (BOREHOLE).
31 SAME LOCATION AS (30), 24" - 36".
32 5 KILOMETERS NORTH OF VALLADOLID, 0" - 12" (BOREHOLE).
33 SAME LOCATION AS (32), 36" - 42".
34 OLD FIELD, 10 KILOMETERS WEST OF CHICHEN ITZA ON MAIN HIGHWAY, 0"-4".

CENTRAL HILL DISTRICT

35 OLD FIELD AT MAYA RUINS OF SAYIL, 0° - 6° (BOREHOLE)
36 SAME LOCATION AS (35), 12° - 18°.
37 CULTIVATED FIELD AT ITURBIDE, 0° - 6°.
38 CULTIVATED FIELD AT HOPELCHEN, 0° - 7°
39 OLD FIELD AT MAYA RUINS OF LABNA, 0° - 12°.
40 CULTIVATED FIELD 1 KILOMETER EAST OF PETO, 0° - 8°.
41 11 KILOMETERS NORTH OF BECANCHEN, OLD FIELD, 0° - 5°.
42 BOREHOLE AT MAYA RUINS OF KABAH, SAMPLE FROM DEPTH 40° - 42°
43 OLD FIELD, 5 KILOMETERS SOUTHEAST OF OXKUTZCAB, 24° - 36° (BOREHOLE).
44 SAME LOCATION AS (43), 0° - 12°.
45 CULTIVATED FIELD, 7 KILOMETERS EAST OF HOPELCHEN, SURFACE SAMPLE IN POLJE BASIN. ONE KILOMETER WEST OF LOCATION (38).
46 BOREHOLE AT MAYA RUINS OF KABAH, SAMPLE FROM DEPTH 28° - 32°.

MONTMORILLONITE CLAYS EXPOSED IN SOUTHERN YUCATAN

47 BLACK CLAYS EXPOSED ON CHETUMAL-ESCARCEGA HIGHWAY AT KM-111
48 SAME AS ABOVE, SAMPLE COLLECTED AT KM-160
49 SAME AS ABOVE, SAMPLE COLLECTED AT KM-188
50 SAME AS ABOVE, COLLECTED 5 KILOMETERS WEST OF CHETUMAL INTERSECTION
51 SAME AS ABOVE, COLLECTED 8 KILOMETERS WEST OF CHETUMAL INTERSECTION.
52 WESTERN SIDE OF YUCATAN PENINSULA, 45 KILOMETERS NORTH OF ESCARCEGA. SAMPLE TAKEN FROM BOREHOLE AT DEPTH OF 36° - 42°.

GUATEMALA

53 SAMPLE G-19-4, BOREHOLE, 105° - 151°, 2 KILOMETERS NORTH OF TIKAL
54 SAMPLE G-19-1, SAME LOCATION AS (53), 0° - 57°.
55 SAMPLE G-19-2, SAME LOCATION AS (53), 58° - 71°.
56 SAMPLE G-24-1, 10 KILOMETERS SOUTHWEST OF FLORES, BOREHOLE, 0°-32°
57 SAMPLE G-24-4, SAME LOCATION AS (56), 83° - 88°
58 SAMPLE G-24-5, SAME LOCATION AS (56), 89° - 108°
59 SAMPLE G-4-1, FIELD, 1 KILOMETER NORTH OF LA LIBERTAD, BOREHOLE, 0° - 32°.
60 SAMPLE G-4-4, SAME LOCATION AS (59), 77° - 110.
61 SAMPLE G-14-8, 6 KILOMETERS NORTH OF SAND ANDRES, BOREHOLE IN OLD FIELD, 135° - 149°.
62 EXPOSURE OF FINELY LAMINATED, WHITE CLAY IDENTIFIED AS PALYGORSKITE ON NORTH SHORE OF LAKE PETEN ITZA.
63 SAMPLE G-20-2, FIELD, 8 KILOMETERS WEST OF FLORES, BOREHOLE, 0° - 24°
64 SAMPLE G-20-3, SAME LOCATION AS (63), 80° - 115°.
65 SAMPLE G-20-6, SAME LOCATION AS (63), 205°-215°.
66 SAMPLE GT-9-1, COLLUVIAL LIMESTONE SOIL 1 FOOT BENEATH SURFACE ORGANIC ZONE, 12.5 KILOMETERS SOUTH OF COBAN. CHANNEL SAMPLE OF 1 FT INTERVAL EXPOSED IN ROADCUT ON HW 5.
67 SAMPLE GT-2-1, 15.5 KILOMETERS EAST OF SAND PEDRO CARCHA (SIERRA DE CHAMA. SAMPLE FROM UPPER 15° ORGANIC ZONE EXPOSED ON SIDE OF TRAIL
68 SAMPLE GT-5-1, 7 KILOMETERS EAST OF SAN PEDRO CARCHA (SIERRA DE CHAMA) 7.5 FT. EXPOSURE IN OLD ROAD CUT. SAMPLE FROM UPPER 14°.
69 13 KILOMETERS EAST OF SAN PEDRO CARCHA (SIERRA DE CHAMA). 8 FOOT EXPOSURE IN CUT ALONG SMALL TRAIL. SAMPLE FROM 1 FOOT INTERVAL JUST BENEATH 14° SURFACE LAYER (A-HORIZON).
70 SAME LOCATION AS (69), 1 FOOT CHANNEL SAMPLE BENEATH (69).
71 SAME LOCATION AS (69), 1 FOOT CHANNEL SAMPLE BENEATH (70), GT-3-4
72 SAMPLE G-22-2, 1.5 KILOMETERS NORTH OF INTERSECTION OF HW 5 AND MAIN ROAD TO FLORES. BOREHOLE, 18° - 48°.
73 SAMPLE G-22-1, SAME LOCATION AS (72), 0° - 18°.
74 SAMPLE COLLECTED FROM THIN (LESS THAN 4°) BLACK SOILS AT TIKAL
75 SAMPLE G-19-3, 2 KM. NORTH OF TIKAL, BOREHOLE, 71° - 105°.
76 SAMPLE G-17-1, BOREHOLE 1.5 KILOMETERS SOUTHEAST OF LAKE PETEN ITZA AND 1 KM. SOUTH OF MAIN ROAD TO BENQUE VIEJO, 0° - 38°.
77 SAMPLE G-13-1, BOREHOLE 3 KILOMETERS NORTH OF SAN ANDRES, 0° - 41°
78 SAMPLE COLLECTED NEAR EL RANCHO, SOUTH OF COBAN. 40° CHANNEL SAMPLE OF THICK SOIL PROBABLY DEVELOPED ON SERPENTINE.
79 SAMPLE GD-1-3, OLD FIELD, 22 KILOMETERS SOUTH OF SANTA ANA, BOREHOLE 12° - 36°.

SAMPLE	SODIUM	POTASSIUM	RUBIDIUM	CESIUM	BARIUM	SCANDIUM	LANTHANUM
1.000	0.052	0.747	82.100	4.760	305.000	18.700	41.500
2.000	0.060	1.940	176.000	11.700	357.000	30.800	77.200
3.000	0.038	0.461	87.400	8.690	202.034	33.700	53.900
4.000	0.077	0.478	34.400	2.570	143.000	9.380	21.600
5.000	0.064	1.370	127.000	9.190	466.000	33.500	76.500
6.000	0.045	0.629	57.500	3.640	178.000	15.800	36.000
7.000	0.142	1.230	95.200	5.850	298.000	20.900	48.300
8.000	0.108	0.714	63.700	4.670	235.000	13.100	25.400
9.000	0.074	1.310	103.000	6.450	345.000	21.700	50.200
10.000	0.096	1.830	158.000	12.100	482.000	30.700	78.000
11.000	0.074	0.547	86.200	11.900	73.800	31.500	91.900
12.000	0.047	0.517	45.200	5.340	134.000	18.500	61.400
13.000	0.054	1.140	132.000	9.720	230.000	28.200	61.000
14.000	0.087	0.968	118.000	11.600	202.034	47.200	108.000
15.000	0.046	1.830	116.000	7.250	236.000	21.900	55.500
16.000	0.069	1.270	155.000	11.800	301.000	45.400	102.000
17.000	0.224	0.704	101.000	9.740	136.000	29.600	34.200
18.000	0.075	1.570	208.000	11.100	407.000	32.100	104.000
19.000	0.082	0.550	102.000	8.630	315.000	30.500	94.600
20.000	0.066	1.090	112.000	7.830	307.000	37.600	103.000
21.000	0.080	1.080	135.000	13.300	474.000	39.200	110.000
22.000	0.063	1.280	130.000	8.300	229.000	30.200	85.600
23.000	0.094	1.230	146.000	10.800	296.000	36.000	94.400
24.000	0.071	0.589	78.700	10.200	103.000	37.500	82.200
25.000	0.095	0.823	113.000	13.100	305.000	34.900	87.200
26.000	0.090	1.010	130.000	11.900	321.000	37.200	79.100
27.000	0.068	1.640	154.000	8.280	213.000	31.100	70.400
28.000	0.061	0.303	50.900	10.500	202.034	36.600	110.000
29.000	0.056	0.582	91.600	9.230	128.000	36.200	91.900
30.000	0.068	0.929	126.000	8.690	302.000	34.100	79.500
31.000	0.091	1.040	130.000	11.200	206.000	39.700	90.700
32.000	0.070	0.925	140.000	13.300	157.000	45.200	101.000
33.000	0.067	0.419	65.200	10.200	188.000	37.200	78.400
34.000	0.083	1.030	133.000	13.200	230.000	36.500	83.500
35.000	0.650	0.513	70.200	6.940	188.000	34.700	107.000
36.000	0.067	0.332	74.900	10.100	196.000	41.400	122.000
37.000	0.047	0.364	41.800	6.620	506.000	32.700	103.000
38.000	0.048	0.706	78.600	6.720	185.000	30.400	94.300
39.000	0.071	0.585	66.800	7.040	180.000	28.600	87.500
40.000	0.063	1.280	130.000	8.300	229.000	30.200	85.600
41.000	0.063	1.070	108.000	7.450	192.000	26.300	84.100
42.000	0.069	0.604	94.500	9.860	201.000	34.700	85.400
43.000	0.068	0.929	126.000	8.690	302.000	34.100	79.500
44.000	0.091	1.040	130.000	11.200	206.000	39.700	90.700
45.000	0.043	0.174	31.800	7.560	323.000	31.800	79.100
46.000	0.097	0.664	75.200	8.600	155.000	34.300	89.600
47.000	0.065	2.950	132.000	6.540	424.000	23.300	47.400
48.000	0.115	1.020	89.300	6.110	387.000	17.000	83.300
49.000	0.022	0.088	8.700	0.657	336.000	2.420	10.400
50.000	0.035	0.665	41.700	2.460	202.034	20.200	77.300
51.000	0.443	0.233	38.600	4.060	2130.000	21.200	35.400
52.000	0.207	1.730	127.000	8.110	136.000	23.000	31.800

SAMPLE	SODIUM	POTASSIUM	RUBIDIUM	CESIUM	BARIUM	SCANDIUM	LANTHANUM
53.000	0.212	0.121	27.100	3.800	204.000	18.800	34.900
54.000	0.056	0.089	22.100	3.220	148.000	17.400	34.600
55.000	0.111	0.166	33.800	2.810	260.000	18.500	39.000
56.000	0.019	0.166	23.329	0.876	202.034	33.500	44.200
57.000	0.021	0.166	23.329	0.762	202.034	36.500	29.400
58.000	0.019	0.166	23.329	1.160	202.034	31.100	25.300
59.000	0.021	0.166	23.329	1.410	202.034	35.400	31.700
60.000	0.028	0.166	23.329	1.090	202.034	33.100	51.800
61.000	2.000	0.156	23.329	2.220	199.000	18.200	48.800
62.000	0.025	1.550	40.300	1.190	184.000	10.800	26.800
63.000	0.022	0.166	23.329	0.689	202.034	34.800	9.060
64.000	0.025	0.166	23.329	1.210	131.000	36.600	10.100
65.000	0.076	0.508	73.500	9.480	140.000	32.400	92.000
66.000	0.520	0.384	24.100	3.070	1360.000	31.000	32.800
67.000	0.149	0.178	6.990	2.640	254.000	31.600	21.900
68.000	0.162	0.205	21.800	2.230	262.000	31.200	20.000
69.000	0.165	0.154	9.340	1.960	212.000	40.500	33.700
70.000	0.255	0.323	23.329	2.010	164.000	45.500	14.600
71.000	0.109	0.147	14.300	2.580	195.000	40.600	19.300
72.000	0.012	0.025	23.329	0.451	46.100	29.100	17.600
73.000	0.016	0.030	23.329	0.902	70.500	33.700	26.600
74.000	0.036	0.081	8.770	0.911	260.000	1.830	5.130
75.000	0.160	0.106	12.800	2.670	212.000	18.800	37.300
76.000	0.039	0.108	18.900	2.230	236.000	17.500	39.000
77.000	0.046	0.088	12.800	2.240	258.000	20.900	50.400
78.000	0.037	0.166	23.329	2.152	59.100	36.000	5.190
79.000	0.039	0.126	23.329	2.152	202.034	56.700	7.710

SAMPLE	CERIUM	EUROPIUM	LUTETIUM	HAFNIUM	THORIUM	TANTALUM	CHROMIUM
1.000	93.600	1.560	0.512	4.290	15.000	0.773	182.000
2.000	163.000	2.620	0.916	8.340	27.200	2.220	229.000
3.000	250.000	2.090	0.941	13.100	31.200	2.160	176.000
4.000	44.400	1.000	0.318	2.390	7.390	0.738	146.000
5.000	170.000	2.580	0.968	8.630	26.800	1.010	292.000
6.000	77.300	1.310	0.424	4.010	12.500	0.664	143.000
7.000	101.000	1.600	0.760	4.830	16.300	1.480	222.000
8.000	58.600	1.170	0.331	3.410	8.860	0.767	93.100
9.000	103.000	1.930	0.711	5.740	16.100	1.090	212.000
10.000	167.000	3.100	0.937	8.640	26.200	1.690	207.000
11.000	187.000	2.930	1.210	12.500	30.000	1.740	286.000
12.000	113.000	2.120	0.716	7.950	17.300	0.934	246.000
13.000	131.000	2.390	0.794	6.990	22.400	1.660	342.000
14.000	237.000	4.060	1.370	12.500	38.300	1.650	412.000
15.000	119.000	2.170	0.689	6.010	18.200	1.810	202.000
16.000	230.000	3.640	1.330	10.200	35.300	2.230	413.000
17.000	206.000	1.210	0.733	9.550	31.900	1.660	388.000
18.000	199.000	3.450	1.310	9.840	32.100	2.350	303.000
19.000	175.000	3.100	1.430	7.280	25.900	3.040	431.000
20.000	215.000	3.560	1.200	7.990	33.600	2.030	354.000
21.000	224.000	3.550	1.450	12.300	33.900	2.880	405.000
22.000	189.000	2.870	1.040	13.000	26.800	1.660	269.000
23.000	191.000	3.170	1.220	8.410	25.500	1.970	337.000
24.000	193.000	3.190	1.250	10.600	28.500	3.080	384.000
25.000	170.000	3.040	1.070	7.240	25.500	1.840	302.000
26.000	175.000	3.050	1.140	8.250	26.100	3.860	325.000
27.000	169.000	2.230	0.943	7.320	25.900	1.450	256.000
28.000	218.000	3.890	1.580	12.100	29.400	4.110	336.000
29.000	193.000	3.680	1.210	6.940	26.200	2.810	391.000
30.000	164.000	2.980	1.090	9.730	28.100	1.620	288.000
31.000	202.000	3.320	1.280	10.900	31.400	1.180	346.000
32.000	212.000	4.200	1.330	9.410	33.200	1.970	450.000
33.000	165.000	3.000	1.070	7.650	25.100	2.430	423.000
34.000	180.000	3.030	1.100	8.950	28.700	2.110	361.000
35.000	235.000	3.390	1.630	13.700	38.100	1.490	924.000
36.000	239.000	4.190	1.730	12.500	41.100	1.810	366.000
37.000	260.000	2.970	1.710	11.500	31.400	2.760	90.100
38.000	259.000	2.940	1.230	14.500	31.400	2.500	252.000
39.000	185.000	2.850	1.360	9.660	27.100	3.150	555.000
40.000	189.000	2.870	1.040	13.000	26.800	1.660	269.000
41.000	205.000	2.590	1.050	11.300	28.500	2.770	134.000
42.000	175.000	3.140	1.100	10.300	29.200	3.050	290.000
43.000	164.000	2.980	1.090	9.730	28.100	1.620	288.000
44.000	202.000	3.320	1.280	10.900	31.400	1.180	346.000
45.000	223.000	2.840	1.390	12.200	33.300	2.930	321.000
46.000	178.000	3.400	1.360	9.810	29.600	2.360	326.000
47.000	103.000	1.730	0.654	6.460	13.800	0.806	223.000
48.000	174.000	2.620	0.764	7.870	16.500	1.190	71.800
49.000	18.900	0.394	0.141	0.955	1.690	0.164	18.400
50.000	146.000	2.480	1.080	8.110	17.300	1.417	164.000
51.000	68.100	1.380	0.636	6.800	13.300	1.660	220.000
52.000	77.300	1.360	0.537	6.690	17.300	1.530	227.000

SAMPLE	CERIUM	EUROPIUM	LUTETIUM	HAFNIUM	THORIUM	TANTALUM	CHROMIUM
53.000	69.800	1.360	0.539	5.690	12.000	0.882	83.600
54.000	74.600	1.450	0.513	5.660	11.700	0.764	81.100
55.000	78.600	1.380	0.550	5.760	12.100	0.877	85.800
56.000	128.000	2.140	0.943	14.000	23.500	1.830	127.000
57.000	141.000	1.220	0.643	12.300	25.300	1.520	164.000
58.000	78.400	1.050	0.547	12.600	22.500	0.874	103.000
59.000	90.800	1.370	0.660	11.500	23.200	1.470	136.000
60.000	139.000	2.150	0.866	10.600	20.800	2.110	97.400
61.000	103.000	1.610	0.543	6.580	12.300	0.881	52.700
62.000	66.000	0.432	0.367	6.450	22.500	0.920	8.630
63.000	21.500	0.243	0.365	12.000	21.600	1.570	106.000
64.000	23.500	0.294	0.369	13.100	25.600	1.900	108.000
65.000	178.000	2.960	1.230	11.800	31.000	2.080	442.000
66.000	149.000	1.330	0.601	8.460	20.600	1.260	25.400
67.000	69.000	0.993	0.468	10.000	15.000	1.270	46.300
68.000	61.100	1.170	0.729	9.190	17.400	1.440	35.700
69.000	69.700	1.850	0.666	10.900	16.600	1.340	36.500
70.000	106.000	1.100	0.710	11.500	23.400	1.400	32.100
71.000	100.000	1.240	0.650	9.880	26.000	1.810	33.000
72.000	33.900	0.677	0.244	10.500	35.200	1.140	208.000
73.000	49.400	0.903	0.416	14.800	28.300	2.090	142.000
74.000	8.350	0.184	0.085	0.614	1.260	1.344	12.400
75.000	75.900	1.490	0.616	5.350	11.900	0.942	86.700
76.000	84.300	1.580	0.618	5.290	10.500	0.816	46.200
77.000	162.000	1.810	0.821	12.700	16.700	1.060	82.900
78.000	14.400	0.534	0.282	0.739	0.962	1.344	4800.000
79.000	18.100	0.345	0.250	4.980	3.460	1.344	47.100

SAMPLE	MANGANESE	IRON	COBALT	ANTIMONY	ZINC	SAMARIUM	YTTERBIUM
1.000	899.000	4.630	13.800	1.606	66.900	7.270	3.230
2.000	1040.000	7.100	18.400	1.990	66.200	12.600	7.470
3.000	1930.000	8.750	29.200	2.940	123.000	11.600	7.170
4.000	481.000	2.410	6.880	0.542	85.400	3.930	1.820
5.000	1300.000	8.260	21.600	1.606	86.500	12.400	5.870
6.000	713.000	3.870	11.700	1.606	83.858	6.150	2.700
7.000	692.000	4.990	12.300	0.844	83.858	6.340	3.700
8.000	613.000	3.480	7.790	1.606	73.700	4.340	2.150
9.000	420.000	5.140	12.700	0.646	83.858	6.650	3.940
10.000	1230.000	7.770	18.500	0.537	74.900	12.800	6.650
11.000	1510.000	7.720	20.800	3.400	105.000	14.900	8.400
12.000	1300.000	5.360	15.800	2.130	79.500	10.300	5.520
13.000	988.000	6.880	16.000	1.430	86.500	10.700	5.730
14.000	1290.000	11.100	27.900	1.606	74.040	17.600	8.220
15.000	822.000	5.310	15.300	1.606	56.700	9.720	5.270
16.000	1660.000	11.000	28.100	1.606	102.000	17.300	7.930
17.000	1160.000	8.700	27.300	1.730	124.000	5.810	4.380
18.000	890.000	7.290	16.200	1.730	101.610	16.900	8.170
19.000	847.000	6.970	16.000	1.730	101.610	14.200	7.900
20.000	1840.000	8.600	27.100	1.730	101.610	16.000	7.400
21.000	952.000	8.560	22.300	1.250	101.610	19.000	10.400
22.000	2190.000	8.830	30.100	1.730	106.000	14.400	6.320
23.000	2300.000	9.770	29.900	1.360	89.900	14.700	7.750
24.000	1570.000	9.230	24.200	3.000	101.610	14.400	8.080
25.000	1650.000	8.870	19.100	0.894	59.600	13.900	7.690
26.000	2060.000	8.940	24.700	1.730	99.800	12.800	6.910
27.000	2100.000	8.340	23.900	1.730	127.000	11.300	5.270
28.000	2240.000	9.590	28.000	3.420	101.610	16.900	8.680
29.000	1590.000	8.230	23.000	1.190	101.610	15.500	7.860
30.000	1410.000	8.620	20.100	1.730	89.500	13.800	6.760
31.000	1280.000	10.000	22.900	1.730	120.000	16.100	7.500
32.000	1370.000	9.790	26.200	1.800	101.610	17.400	9.960
33.000	1300.000	9.400	22.400	1.290	83.300	13.100	7.650
34.000	2150.000	8.880	25.000	1.370	117.000	13.300	8.020
35.000	3400.000	9.420	33.500	3.146	136.000	19.100	10.300
36.000	2580.000	9.370	32.300	3.146	155.000	21.400	10.800
37.000	2810.000	7.210	23.800	3.090	114.186	14.600	8.890
38.000	2090.000	8.520	27.400	2.850	114.186	15.200	8.220
39.000	2380.000	7.420	24.500	5.080	114.186	13.900	7.440
40.000	2190.000	8.830	30.100	3.146	106.000	14.400	6.320
41.000	1890.000	6.730	19.900	1.870	114.086	13.800	6.490
42.000	2000.000	8.560	25.000	2.630	73.800	14.400	8.500
43.000	1410.000	8.620	20.100	3.146	89.500	13.800	6.760
44.000	1280.000	10.000	22.900	3.146	120.000	16.100	7.500
45.000	3060.000	7.900	21.700	3.380	119.000	14.600	8.780
46.000	2470.000	8.550	24.400	3.120	114.086	16.000	8.010
47.000	1720.000	5.670	33.300	0.807	82.500	7.980	4.720
48.000	1000.000	4.050	15.600	1.230	75.200	13.500	6.320
49.000	399.000	0.551	3.430	0.283	12.600	1.990	0.893
50.000	2160.000	6.160	24.000	1.413	97.200	12.400	5.750
51.000	637.000	5.210	16.500	1.110	73.500	6.510	3.800
52.000	369.000	5.620	10.800	1.440	79.900	6.060	3.920

SAMPLE	MANGANESE	IRON	COBALT	ANTIMONY	ZINC	SAMARIUM	YTTERBIUM
53.000	1280.000	4.600	13.200	0.887	76.600	6.540	3.990
54.000	1320.000	4.300	13.200	1.080	82.000	6.380	3.900
55.000	1640.000	4.590	15.400	1.230	75.700	7.110	3.990
56.000	1240.000	8.770	16.000	2.030	102.000	8.480	5.930
57.000	2930.000	10.400	40.000	7.362	126.000	5.920	3.280
58.000	556.000	6.530	10.100	7.362	94.500	4.790	3.190
59.000	338.000	9.140	17.000	7.362	121.000	6.860	3.680
60.000	695.000	7.970	13.600	2.280	82.571	8.820	5.170
61.000	652.000	4.110	13.300	1.260	82.571	6.910	3.640
62.000	179.000	2.210	7.170	7.362	53.800	3.780	2.430
63.000	77.200	7.380	3.930	2.440	66.500	1.250	1.370
64.000	123.000	7.330	4.890	2.230	74.000	1.470	1.710
65.000	2200.000	8.070	24.600	4.550	110.000	15.600	9.280
66.000	1050.000	8.680	21.700	2.170	82.571	7.020	4.540
67.000	421.000	9.320	16.800	1.720	82.571	4.610	3.390
68.000	1160.000	8.340	15.300	1.550	82.571	5.550	4.190
69.000	907.000	10.800	16.400	0.981	73.039	7.510	5.300
70.000	599.000	11.300	16.600	1.540	82.571	5.500	5.180
71.000	1130.000	10.900	11.400	1.480	82.571	5.850	5.130
72.000	316.000	33.600	4.530	2.860	82.571	3.220	3.190
73.000	281.000	16.600	5.240	2.890	82.571	4.200	3.790
74.000	364.000	0.444	2.360	0.260	25.800	0.966	0.434
75.000	1360.000	4.580	14.100	1.070	80.000	6.980	3.410
76.000	1290.000	4.290	14.000	0.889	68.100	6.940	3.570
77.000	2670.000	5.270	23.300	0.818	82.571	8.880	4.630
78.000	1560.000	13.200	169.000	0.597	82.571	1.660	1.460
79.000	824.000	11.100	11.800	7.362	82.571	1.290	1.010

SUMMARY STATISTICS FOR TRACE ELEMENT DATA

Mean Value

	SODIUM	POTASSIUM	RUBIDIUM	CESIUM	BARIUM	SCANDIUM	LANTHANUM	CERIUM	EUROPIUM	LUTETIUM
Yucatan Smectites	0.148	1.114	72.883	4.656	602.506	17.853	47.683	97.883	1.661	0.635
Guatemala	0.162	0.218	23.329	2.152	232.183	29.334	29.959	81.235	1.217	0.566
Cent. Hill Dist.	0.115	0.688	85.650	8.257	238.583	33.242	92.317	209.500	3.123	1.331
NE Cstl. Plain	0.084	0.933	119.244	10.528	251.057	35.633	87.761	191.111	3.140	1.191
NW Cstl. Plain	0.071	1.061	102.294	7.952	261.742	26.311	61.775	140.306	2.267	0.808

Standard Deviation

Yucatan Smectites	0.160	1.076	50.912	2.784	756.383	7.896	28.195	56.008	0.821	0.306
Guatemala	0.383	0.284	12.296	1.707	232.837	11.550	18.456	46.481	0.657	0.240
Cent. Hill Dist.	0.169	0.334	32.795	1.487	97.727	4.304	12.604	33.102	0.416	0.250
NE Cstl. Plain	0.037	0.368	35.797	1.858	98.098	3.936	17.543	19.128	0.649	0.198
NW Cstl. Plain	0.027	0.508	41.268	3.293	113.501	10.763	25.574	63.227	0.869	0.322

Mean Value

	HAFNIUM	THORIUM	TANTALUM	CHROMIUM	MANGANESE	IRON	COBALT	ANTIMONY	ZINC	SAMARIUM	YTTERBIUM
Yucatan Smectites	6,148	13.315	1.128	154.033	1047.500	4.544	17.272	0.974	70.150	8.073	4.234
Guatemala	8.998	18.199	1.344	267.760	1006.007	8.660	19.812	2.727	82.218	5.707	3.733
Cent. Hill Dist.	11.592	31.333	2.273	346.758	2296.667	8.428	25.467	3.146	114.169	15.608	8.168
NE Cstl. Plain	9.303	28.767	2.336	352.722	1605.500	8.812	23.800	1.730	101.610	14.417	7.594
NW Cstl. Plain	7.471	21.816	1.414	237.694	1055.500	6.486	17.298	1.606	83.245	10.288	5.361

Standard Deviation

Yucatan Smectites	2.631	5.955	0.560	89.096	740.485	2.082	10.383	0.402	29.421	4.282	1.915
Guatemala	3.821	8.618	0.417	909.728	740.123	6.108	30.788	2.413	19.018	3.100	1.775
Cent. Hill Dist.	1.615	4.365	0.686	215.507	625.813	0.965	4.493	0.725	20.240	2.349	1.404
NE Cstl. Plain	1.872	3.134	0.814	56.339	487.392	0.799	4.101	0.602	15.582	2.859	1.418
NW Cstl. Plain	3.368	9.266	0.559	91.555	432.413	2.534	2.534	6.835	16.236	4.267	2.207

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